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16. Abstract

This project developed a computer system to assist Louisiana Department of Transportation and Development (LA DOTD) maintenance managers in the preparation of zero-based, needs-driven annual budget plans for routine maintenance. This includes pavement, roadside, bridge maintenance, traffic operations & assistance to traffic, and ferry operations. The budget plan provides estimates for labor, overhead, equipment, and supply costs as well as contract maintenance. The computer system provides management with ability to set planned service level targets for each maintenance function and to prioritize importance of both maintenance functions as well as use-based measures. It includes an optimization model that assists in allocating constrained financial resources among functions and districts based on these priorities and needs. It also includes a regression tool which can be used to automatically update the planning model based on recent historical data.

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LOUISIANA DOTD MAINTENANCE BUDGET ALLOCATION SYSTEM

FINAL REPORT

by

GERALD KNAPP
Fred B. and Ruth B. Zigler Associate Professor of Engineering

LAWRENCE MANN, JR.
Edward McLaughlin Professor of Engineering

Department of Industrial & Manufacturing Systems Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

LTRC Project No. 98-20SS

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ABSTRACT

This project developed a computer system to assist Louisiana Department of Transportation and Development (LA DOTD) maintenance managers in the preparation of zero-based, needs-driven annual budget plans for routine maintenance. This includes pavement, roadside, bridge maintenance, traffic operations & assistance to traffic, and ferry operations. The budget plan provides estimates for labor, overhead, equipment, and supply costs as well as contract maintenance.

The computer system provides management with ability to set planned service level targets for each maintenance function and to prioritize importance of both maintenance functions as well as use-based measures. It includes an optimization model that assists in allocating constrained financial resources among functions and districts based on these priorities and needs. It also includes a regression tool which can be used to automatically update the planning model based on recent historical data.

IMPLEMENTATION STATEMENT

The results of this work have been implemented in the form of a PC-based decision support system for assisting routine maintenance budget planning/allocation. This software can be directly installed and utilized by DOTD maintenance management.

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INTRODUCTION

Problem Statement

The LA DOTD currently lacks a functional computer model for allocating annual maintenance funds to the districts based on need rather than history. A model is required which will allocate limited maintenance funds as effectively as possible, as well as provide the LA DOTD with a rational decision process which can be used in justifying and defending allocation decisions to the state legislature and Louisiana's citizens.

Related Work

In December 1957, the Louisiana Department of Highways published a pamphlet entitled "Formula for Allocating Maintenance Funds" [*48*]. That work was the result of an investigation made by Mr. E.A. Landry of that department. He recognized that a relationship might exist and submitted the problem to the Division of Engineering Research at LSU. The investigation was completed in late 1962. The research did not yield a mathematical model to predict maintenance costs for concrete surfaces because of the limited scope of the project. The investigation, however, did show that five main effects appeared to account for much of the variability in maintenance costs: traffic volume, surface condition, subsoil condition, surface width, and right-of-way width.

In 1966, the report "Maintenance Formula for Asphalt Roads" was issued (State Project No. 736-00-64; FAP No. HPR-1(2)). It concludes with a model, although the fit is less satisfactory than the concrete model.

From 1965 to 1970, the consulting organization, Roy Jorgensen and Associates, conducted a study to design a maintenance management system for Louisiana (State Project No. 736-00-74). Budget cuts have since precluded the implementation of much of that study.

The Federal Highway Administration (FHWA) and the states, beginning in 1978, jointly developed and implemented a continuous data collection system called the Highway Performance Monitoring Systems (HPMS), but research on performance budgeting started well before that. Highway agencies at all levels of government have sponsored research involving one or more of the basic performance budgeting concepts. Analytical techniques have varied from those with a relatively simple cost accounting orientation to those dependent on quantitative analysis. Basically, two different approaches to performance budgeting were found in the literature survey. One is principal emphasis on work methods, production rates, and work scheduling and the other is the "total systems" approach. The following general characteristics were found in the literature survey:

a) Used work scheduling.

b) Recognized the importance of formalizing and integrating all performance budgeting elements.

c) Employed quantitative work measurement techniques.

The Transportation Research Board's (TRB) Pavement Management Handbook describes the application of different maintenance concepts in details. This also addresses the technology behind the pavement sealers, joint sealers, and processes in crack filling, patching, stripping, and so on.

TRB report 215 defines a pavement management system as a tool that provides decision makers at all levels of management with optimum maintenance strategies derived through clearly established rational procedures [*36*]. The report also laid out a framework for developing a pavement management system with a detailed description on characteristics for input models and output, provides alternative pavement management system viewpoints, and discusses specific existing technologies for PMS.

Maintenance levels of service influence the magnitude of the maintenance work (e.g., pavement patching, mowing, paint striping) and, therefore, the work scheduling requirements, work priorities, and resource allocations. However, selection of maintenance levels of service is influenced by a number of considerations that include safety, rideability, economics, environmental impact, protection of investment, and aesthetics. Thus to optimize the expenditure of maintenance resources, the TRB developed a systematic and objective method, based on decision analysis theory, to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structure, drainage ditches, etc.). These guidelines were published in the TRB Report No. 223 in 1980 [*25*].

Kulkarni et al. developed a systematic methodology for determining the maintenance levels of service that would maximize the user benefits subject to the constraints of available resources. [*22*]

As a continuation of the work done in 1980 on developing the guidelines for determining maintenance levels-of-service, the TRB developed a user's manual to instruct the maintenance personnel on the implementation of a simplified method to determine the optimal maintenance levels of service, given resource constraints of labor, material, and equipment. This manual was published in the TRB Report No. 273 in 1984 [*31*].

Since 1984, Highway Maintenance Management Systems have continually been developed and refined. However, because of inflation and limited funds, highway agencies have not been able to sufficiently fund maintenance to provide satisfactory levels of service. Realizing this, the Transportation Research Board conducted a study in 1986 to address the need of developing a method that could be used to evaluate agency and user costs resulting from decisions regarding maintenance service levels and rehabilitation timing. Life-cycle analysis (based on life-cycle costs) was identified as an effective method for such evaluations. This method is used to compute, for specified maintenance service levels, agency costs, vehicle-operating costs, traffic-interference costs, and other consequences such as accidents, lost time, pollution, and inconvenience. The results of this study were published in National Cooperative Highway Research Program Report No. 285 in 1986 [*10*].

Johnston (1988) presents executive summaries of two studies to develop components of a bridge management system [*19*]. In the first, a bridge management analysis method considering owner costs and user costs was developed to determine the optimum improvement action and time for each individual bridge in a system under various level of service goals. A computer program incorporating parameters and relationships of bridge ownership and user costs was created to analyze North Carolina bridges as an example. Based on the optimum improvement alternative selected for each individual bridge, the future funding needs, bridge conditions, load capacity, and bridge level of service deficiencies were predicted under different combinations of maintenance condition level of service goals and user level of service goals. The second study deals with the problem of identifying optimal maintenance levels of service for bridge maintenance activities. A systematic, objective methodology and a non-linear optimization program was utilized to structure and analyze a bridge maintenance model.

The Ohio Department of Transportation has a program of dedicated maintenance funding for various highway projects (1989) [*53*]. Monetary limits are established and enforced for projects ranging from roadside rest area maintenance contracts to two lane resurfacing. Allocation amounts and a brief description of the maintenance or repair requirements are given.

In the late eighties, the Pennsylvania Department of Transportation (PennDOT) piloted a matrix measurement concept developed in Oregon, the "Organizational Performance Index" (OPI) (1996) [*9*]. This tool provides the ability to track performance regularly and determines if improvement is being made based upon some predetermined indicators. Following successful implementation of OPI, PennDOT modified the concept in the early 1990s and applied it to measuring customer satisfaction. PennDOT now uses the Customer Service Index (CSI) throughout the Department to measure performance as determined by its customers.

Mann and Knapp et al. (1997) evaluated Louisiana's current computerized maintenance management systems and recommended improvements [*29*]. They developed a long-term capital outlays budget planning structure for achieving a fully funded maintenance program. Mann and Knapp et al.'s research also revealed that the current CMMS has significant deficiencies in terms of supporting critical maintenance management processes, data quality and integration. They described the present system as an extended version of an accounting support system. Their analysis of current maintenance funding indicated that maintenance in Louisiana was seriously under funded.

Many Texas Department of Transportation (TxDOT) District Engineers had expressed a concern to the Senior Management team about not having enough maintenance funds. In March 1996, the Executive Director developed a "Continuous Improvement" team and charged them with extensively evaluating the Routine Maintenance Budget issue and developing a formula driven process, by category of work, to equitably distribute the routine maintenance budget. The team was to develop "needs-based" formulas for most individual maintenance activities. The budget allocation was made by using fiscal year 1995 data in the formulas. The data needed for the formula is to be updated annually. The budget formulas developed are based upon road inventory and condition, making the process dynamic. As inventories increase or pavement condition scores change, the funding levels change. The districts with the problems get more money. The budget formulas were developed at a "Tolerable" level of funding. The system can be utilized to develop a "Tolerable" estimate of needs. Slight modifications can produce an "Acceptable" or "Desirable" needs estimate. The quantities of work identified in the budget process compare favorably with the existing quantities of work by district. This process results in an equitable level of funding for all districts.

Al-Monsoor et al (1994) studied the effect of various maintenance treatments of flexible pavement condition [*1*]. Pavement roughness was used as direct quantitative measures of pavement condition. A database from the Indiana Department of Transportation (INDOT) was used in this research. Possible factors, which can affect pavement condition, were investigated in this analysis. Maintenance-effect models had been introduced to examine the effect of various maintenance treatments on pavement roughness. A maintenance effectiveness measure was also developed to compare various treatments.

Kardian and Woodward (1990) discuss the maintenance quality evaluation program formally implemented by the Virginia Department of Transportation (1989) to increase the productivity and effectiveness in highway maintenance operations [*21*]. This research qualitatively assessed the level of maintenance for flexible and rigid pavements, stabilized roadways, roadway shoulders, drainage, traffic control and safety, roadside, and structures.

Miquel and Condron (1991) report the results of a joint research study by the United States Federal Highway Administration and the World Bank to assess contract road maintenance practices in selected countries with the objective of providing operational guidance on planning, budgeting, tendering, and administering such works [*32*]. The report describes the reasons for using contract maintenance, the classification of maintenance operations, the selection of work items to be contracted, and the types of contracts used for maintenance works. The procedures for tendering contracts and supervision of works are reviewed. The report further compares contract maintenance with force account work and discusses the transition from force account (direct labor) operation to contract maintenance.

The PAVER system developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) in 1982 provides the ideal environment for creating standardized work plans. The system includes a mainframe version (PAVER) and a microcomputer version (Micro PAVER) to provide the Army installation Directorate of Engineering and Housing (DEH) with an easy-to-use decision making tool for pavement maintenance management. System capabilities include data storage and retrieval, pavement condition prediction, budget planning, determination of Maintenance and Repair (M&R) needs, and economic analysis. The PAVER system can help DEH personnel prioritize the pavement sections requiring maintenance and/or repair. It also helps the engineer to choose the best maintenance and rehabilitation alternative. The goal of this technology is to maximize the pavement condition with the available funds. The pavement condition rating used in PAVER is the Pavement Condition Index (PCI), which is based on the type, quantity, and severity of distresses present. As a part of the implementation of PAVER system, a priority scheme for the selection of pavement sections needing major repair was created. The scheme developed was a “worst-first” priority strategy based on pavement condition and rank. A shortcoming to this scheme is that cost and benefit of repair are not considered as criteria. Although the priority scheme is a vast improvement over past methods, it is simply a “worst-first” method.

If cost were also considered in the selection process, an improvement would result by taking advantage of the fact that as PCI drops, cost for repair increases.

Uzarski and Darter (1986) addressed this issue in their research. They incorporated cost and benefit criteria as additional parameters in the selection of pavement sections for major repair [*51*]. Six strategies were considered: 1) do nothing, 2) use the existing priority scheme, 3) use a revised priority scheme that takes cost into account, 4) repair when needed, 5) use section benefit-cost optimization with variable utility, and 6) use section benefit-cost optimization with constant utility. The research also revealed that by revising the priority strategy or by using benefit-cost optimization techniques, an improved network condition could result at a lower overall cost.

A project of the National Cooperative Highway Research Program (NCHRP) (Project 3-56) titled "System-wide Impact of Safety and Traffic Operations Design Decisions for Resurfacing, Restoration, or Rehabilitation (RRR)" is researching to develop a process for allocating resources to maximize the effectiveness of RRR projects in improving safety and traffic operations on the non-freeway highway network. This project is envisioned to undertake the following: a) critically review the literature to identify the safety and traffic operations impact associated with RRR projects; b) contact federal and state agencies to identify their policies, standards and programs associated with RRR projects; c) conceptualize a process to maximize the cost-effectiveness of RRR projects under the constraints of limited resources; d) compare the data requirements defined for the process with the types of data currently available; e) gather the data needed in accordance with the plan approved by the panel; f) develop the process for evaluating the cost-effectiveness of safety and traffic operations improvements associated with RRR projects; g) demonstrate the process by applying it to a representative set of projects in cooperation with three or more agencies. This information was made available through a posting of the status report and objective on the Internet.

The "Trunk Road and Maintenance Manual" (1992), a publication of the United Kingdom's Department of Transport, deals with several aspects of routine highway maintenance [*50*]. Volume 1 provides sections on routine maintenance management, minor carriageway repairs, footways and cycle tracks, curbs, edgings, pre-formed channels, drainage, motorway communications installations, as well as other topics. Volume 2 covers maintenance of highway structures such as bridges, subways and underpasses, retaining walls, sign signal gantries, and high masts and catenary lighting.

Sinha and Fwa (1993) present the results of a research study, the objective of which was to develop a systematic decision-making framework to enhance the efficiency and effectiveness of the existing highway maintenance management practices in Indiana [*45*]. The required forms of data and the recommended basis and procedures of decision making are discussed for the following: assessment of maintenance needs; establishment of performance standards; determination of costs of maintenance treatments; setting up an integrated database; priority rating maintenance activities; and optimally programming and scheduling maintenance activities. The proposed framework intends to help management plan and monitor highway maintenance programs to achieve better results.

Sutarwala and Mann (1963) were the first to develop a conceptual mathematical model in the form of an equation that could predict the yearly maintenance cost of a given mile of roadway section [*48*]. Mann (1963) continues the work in this area and develops a mathematical model to predict highway maintenance costs by modifying the initial model to ensure the adequacy of maintenance [*27*]. He suggests that the mathematical model could be used to compute future maintenance requirements and to calculate the costs within various activity classifications (patching, grass cutting, etc.).

The Highway Research Board Report No. 42, published in 1967, presents the development of a unit maintenance expenditure index, expected to be useful to a highway administrator or engineer in evaluating past and predicting future highway maintenance costs trends [*18*]. It further recommends that a new Unit Labor Cost Index, Unit Equipment Cost Index, and a Unit Material Cost Index be established and computed annually.

In the seventies, with numerous highway agencies undertaking the development of systems for improving maintenance management systems, the Highway Research Board realized the need and hence developed a model for maintenance performance budgeting to make budgets effective management tools. The model was developed in accordance with the establishment of maintenance levels; definition of workload; determination of resource requirements; procedures for management planning, evaluation, and control; records and reports to serve the budget system; and simplicity and economy of installation and operation as the basic criteria. This model was published in Highway Research Board Report No. 131 in 1972 [*38*].

To help highway maintenance management plan maintenance activities, Mann et al. (1976) developed a series of models to estimate maintenance costs requirements by applying the least squares technique to a database derived from the historical records maintained by the Louisiana Department of Highways [*30*]. The models could be used to compute the costs of surface maintenance, shoulder and approach maintenance, roadside and drainage maintenance, structure maintenance, traffic surface maintenance, river-crossing operations maintenance, and maintenance overhead and administration costs.

In an attempt to identify and implement efficient highway maintenance operations, the TRB conducted a study of the recording and reporting methods for highway maintenance expenditures used by eleven states. The study shows that numerous types of reports were generated but suggests that reports be categorized as audit, inventory, planning, equipment use, performance, budget control, special analytical, and exception reports. The study recommends that an ideal recording and reporting system should be capable of furnishing maintenance activity and cost information to the highway designer who is concerned with alternative life-cycle analyses. The findings of this study were published in the TRB Report No. 46 in 1977 [*41*].

Niessner (1978) reports a series of value engineering studies performed by the FHWA and the TRB with an aim to optimize the expenditure of maintenance resources [*33*]. The studies include the following maintenance activities: snow and ice control (operations and materials), shoulder maintenance, bituminous patching, repair of continuously reinforced concrete pavement, sign maintenance, bridge painting, pavement markings, repair of pavement joints, and maintenance of rest areas. The studies prove that the value engineering process can be successfully used to perform an in-depth analysis of maintenance activities.

In 1981, the TRB published Report No. 80, which reviews the development of highway maintenance budgets and the steps involved in the approval process of different highway agencies [*12*]. The report also includes a compilation of research needs related to formulating and justifying highway maintenance budgets. These needs include the development of budget tools to relate maintenance expenditures to long-term benefits, cost-effective maintenance strategies, and objective procedures to establish priorities among maintenance deficiencies.

Sharaf and Sinha (1978) develop a methodology for using available state data on traffic, highway system characteristics, and routine pavement maintenance records to develop models relating the cost of routine maintenance to pavement system characteristics [*44*]. The model can therefore assist in preparing a pavement maintenance program and in making decisions regarding the trade-offs between rehabilitation and routine pavement maintenance.

Kampe et al. (1978) develop a new approach to estimate labor resource needs for a highway maintenance program to be used in budgeting [*20*]. Seven calculation methods, including historic projection, frequency calculation, condition evaluation, organization plan, proration, and capital project scheduling plan, are employed to correlate workload and labor resources. The authors suggest that this model be used to make budget recommendations to top management.

Responding to concerns over the inability of capital budgeting models for planning long-term highway maintenance, Cook (1984) develops a financial planning model to determine minimum annual expenditure requirements to meet service level objectives by road category, based on traffic density [*7*]. He also uses goal programming to determine maintenance strategies and allocate funds to achieve target service levels for each road category.

Golabi, et al. (1982) describe a pavement management system which produced both short-term and long-term optimal maintenance policies for the Arizona highway network. [*14*]. The foundation of this pavement management system is a Markov decision model which determines cost-minimizing maintenance schedules for each mile of the system, taking into account management decisions, budget allocations, engineering procedures, and environmental factors such as altitude, temperature, moisture conditions, and traffic density. The authors show that the use of this pavement management system led to the development of reliable predictive performance models that have enhanced understanding of pavement deterioration and effectiveness of various maintenance procedures.

Chong and Phang (1985) discuss the steps taken by the Ontario Highway System to prolong the life of highway pavements [*5*]. Perhaps the most significant contribution of this research is the detailed guidelines for situations in pavement maintenance where preventive maintenance affects the life of pavements. The guidelines consist of the identification process, treatment selection, and performance standards to be used. The research describes the practices of identifying and classifying a typical deficiency, selection of the most cost-effective treatment, specifications for equipment and materials needed to carry out the treatment, and proper work methods.

Theberge (1987) undertook a study to examine the mathematical relationship between a variety of pavement attributes and other quantifiable variables on one hand, and maintenance needs and priority evaluations made by district area supervisors on the other [*49*]. With some assistance from the Maine Department of Transportation and by using the Delphi technique, threshold levels for preventive maintenance, capital maintenance and rehabilitation are established. A model to predict repair categories is also developed.

Poister (1983) discusses the productivity-monitoring program for highway maintenance implemented by the Pennsylvania Department of Transportation, which links productivity to a variety of performance indicators, including output, costs, and highway conditions [*39*]. Decreased labor costs, increased maintenance output, and improved highway conditions were the major benefits gained by implementation of this program.

Cochran et al. (1991) describes a research project funded by the Arizona Department of Transportation that resulted in a decision support system for transportation planners of goods movement on highways [*6*]. They point out that this is the first DSS to include simultaneous embedded computer simulation and database tools to generate summaries of pavement maintenance activities.

Evans et al. (1992) conducted a study aimed at improving the effectiveness and efficiency of routine road maintenance activities by emphasizing a needs-driven approach to determining an optimal arrangement for road maintenance patrol resources [*11*].

Smith et. al. (1996) describes a methodology to develop possible global maintenance strategies for a highway network using the Financial Network Optimization System module from the RTA NSW pavement management system [*46*]. The authors describe their methodology including a discussion of the appropriate condition data to use. They proposed the use of the Maintenance Level of Service (MLOS) developed by the Texas Department of Transportation to assist in the interpretation of the condition data and determine which condition parameter (cracking, rutting, or roughness) is driving the maintenance effort.

OBJECTIVE

The objective of this research is to develop a zero-based budgeting system for routine maintenance expenditures, in which allocations are justified on quantifiable need and management service objectives to equitably and effectively distribute routine maintenance funds to the districts.

SCOPE

The focus of this work will be on the development of a computer model for allocating funds to routine maintenance activities. These activities will include all routine maintenance functions performed in the areas of pavement, roadside, bridges, traffic operations and traffic assistance, and ferries, but specifically exclude consideration of funding for larger reconstruction and major overhaul work on these structures. Supplies and contract maintenance costs relating to routine maintenance will be included in the model.

METHODOLOGY

Following is an overview of the methodology taken in this study:

1. **Data Collection.** Existing data sources were researched and data was collected relevant to the project. This section details what data was collected and what data is required by the planning system.

2. **Base Function Calculations.** Consists of two components:

   - **Maintained Units**. Calculation of the total units under maintenance in each district, system, and maintenance function combination.

   - **Average Unit Accomplishment Cost.** Calculation of the average unit cost of accomplishment for each district, system, and maintenance function for personnel, equipment, and material costs.

3. **Accomplishment Units Prediction Calculations**. Regression and analysis of variance (ANOVA) was applied to develop a regression model for predicting how many units of accomplishment are required for each function at a baseline service level.

4. **Base Function Cost Calculations**. Calculation of total cost model (excluding overheads and fringe) for each maintenance function.

5. **Service Level Calculations**. Identification of service level measurement factors, and development of a predictive relationship between amount of maintenance dollars allocated and service level performance.

6. **Fringe & Overhead Calculations.** Addition of fringe and overhead rates to determine the total maintenance costs by function, district, and quarter.

7. **Function Prioritization Model**. Development of a model for representing effectiveness priorities between functions.

8. **Allocation model.** Development of a budget allocation model for optimizing service levels and/or budget levels.

The following sections detail each of these steps.

Data Collection

Databases

Historical data was collected from the following LA DOTD databases:

- MAINTENANCE OPERATIONS SYSTEM (MOPS) INVENTORY

  The inventory database contains road inventory data by control section/subsection. This data is critical to the accuracy of the maintenance planning model; however, it is not updated frequently and its accuracy is questionable. It also only indicates the inventory at the time of the last update – no inventory history is maintained that can be related back to maintenance requirements and cost for a particular time.

The following data is utilized from this database:

- Length
- Miles Concrete
- Miles Concrete Equiv. 2 Ln
- Miles Asphaltic (bit) Concrete
- Miles Asphaltic (bit) Concrete Equiv. 2 Ln. – P1200 ADT
- Miles Asphaltic (bit) Concrete Equiv. 2 Ln. – M1200 ADT
- Miles Composite
- Miles Composite Equiv. 2 Ln. – P1200 ADT
- Miles Composite Equiv. 2 Ln. – M1200 ADT
- Miles BST (asphalt)
- Miles Gravel
- Miles Shoulder Non-paved Turf
- Miles Shoulder Non-paved Aggregate
- Miles Shoulder Paved
- Miles Mowing Rural
- Miles Mowing Urban
- Miles Sweeper Curb
- Physical Acres
- Vehicle Miles Travel
- Number of Litter Barrels
- Number of Rest Areas
- Number of Crash Devices

During the import process, a sum of each data field except vehicle miles traveled is also created across each unique district/system code combination. A weighted summarization of Vehicle miles is calculated as =Sum(Vehicle Miles*Length)/Sum(Length).

- MOPS WORK ORDER (WO) HISTORY

MOPS WO history data is the basic work order expense and accomplishments data. The import table from the MOPS WO mainframe file includes the following for each unique combination of system, district, parish, gang, function, fiscal year, and control section:

- Fiscal Year
- System
- District
- Parish

- Gang
- Control Section
- Total manhours – regular time (does not include fringe)
- Total manhours – overtime (overtime pay=1.5x regular pay)
- Total personnel costs
- Total equipment costs
- Total material costs
- Total accomplishment quantity

- NEEDS SURVEY

The NEEDS survey database contains data on road condition, deficiency analysis, and improvement planning. It overlaps the MOPS inventory database to some extent, particularly on mileage figures and average daily traffic (ADT), and appears to be more up to date in these aspects, although it still is not updated annually for each control section.

The NEEDS data is primarily used as covariates in the unit accomplishments prediction model.

The NEEDS database gives details down to parts of control section, and the following data is collected.

- Control Section
- Logmile
- Length (miles)
- District
- Parish
- System (Functional Class)
- Lanes
- ADT
- Terrain (0=flat, 1=rolling)
- Condition Rating
- Safety Rating
- Total Rating
- Surface Type
- Pave Type
- Base Type
- Last Year Improved
- Years Since Last Improved (calculated from above as Year(Now)-Last Year Improved)

This data is aggregated on import to the control section level:

- Control Section
- Total section length (miles)

- District
- Parish
- System (Functional Class)
- Avg Lanes = Sum(Lanes*Length*ADT) / Sum(Length*ADT) over all subsections of the control section.
- Avg ADT = Sum(ADT*Length/Lanes) / Sum(Length/Lanes) over all subsections of the control section.
- Avg Terrain = Sum(Terrain*Length) / Sum(Length)
- Avg Condition Rating
- Avg Safety Rating
- Avg Total Rating
- Total Eq Lane Miles (miles) for each surface type = Sum(length*Lanes) by surface type
- Total Eq Lane Miles (miles) for each pavement type = Sum(length*Lanes) by pavement type
- Total Eq Lane Miles (miles) for each base type = Sum(length*Lanes) by base type
- Avg Last Year Improved = Sum(Last Year Improved * Length*Lanes) / Sum(Length*Lanes)
- Avg Years Since Last Improved = Year(Now)-Avg Last Year Improved

- STRUCTURES

The Structures database contains the inventory of bridges and overpasses. For each unique combination of district and summary, the following is required.

- District
- System
- Total Number of bridges
- Total Number of non-timber bridges
- Total Number of timber pile bridges
- Total Number of movable bridges
- Total Bridge length (in miles)
- Total square feet of bridge concrete deck
- ADT & Length Weighted Bridge Condition Rating, all bridges
- ADT & Length Weighted Bridge Condition Rating, Non-Timber
- ADT & Length Weighted Bridge Condition Rating, Timber
- ADT & Length Weighted Bridge Condition Rating, Movable Bridges
- Total Number of Railroad Crossings

- TRAFFIC

  The Traffic signal inventory provides inventory data on traffic signal devices. For each district / system combination, the following is collected:

  - Number of signal devices

- FERRY CROSSINGS

  A list was obtained of ferry crossing locations. The following information is required for each location:

  - District
  - Description

  In addition, a total count of ferry crossings would be calculated for each district.

- TOLLS

  A list was obtained of toll locations. The following information is required for each location:

  - District
  - Description

  In addition, a total count of tolls would be calculated for each district.

All records from each database for 1992-2001 were dumped to text files from the mainframe data stores, and subsequently ported to LSU via FTP. The data was subsequently imported and summarized as needed into Access.

Base Function Calculations

In this section, the procedure for calculating the base number of units under maintenance and the average unit accomplishment cost are detailed. Appendix A provides a brief description of all the maintenance functions and their accomplishment units.

Maintained Units

Following are the calculations used for determining the base number of inventory units maintained by each function. The calculations are performed for each district / system combination by function.

Bituminous Surface Maintenance Functions (411-419)

=Total Miles Asphaltic Concrete Equivalent 2 Lane +
Total Miles Asphaltic Concrete Equivalent 2 Lane P1200 +

Total Miles Asphaltic Concrete Equivalent 2 Lane M1200 +
Total Miles BST

Except for function 418 (cutting/burning bumps):

=Total Miles Asphaltic Concrete Equivalent 2 Lane +
Total Miles Asphaltic Concrete Equivalent 2 Lane P1200 +
Total Miles Asphaltic Concrete Equivalent 2 Lane M1200

Concrete Surface Maintenance (421-429)

=Total Miles PC Concrete Equivalent 2 Lane

Gravel or Shell Surface Maintenance (439)

=Total Miles Gravel

Shoulder Maintenance (441-459)

For functions 441-445 (non-paved shoulder):

=Total Miles Shoulder Non-Paved Turf +
Total Miles Shoulder Non-Paved Aggregate

For functions 452-455 (paved shoulders):

= Total Miles Shoulder Paved

For function 459 (other shoulder maintenance):

=Total Miles Shoulder Paved +
Total Miles Shoulder Non-Paved Turf +
Total Miles Shoulder Non-Paved Aggregate

Roadside and Drainage Maintenance (461-479)

For functions 461-468,471-473,475, 477,479 (general ditch and drainage servicing):

=Total Length

For functions 470,478 (mowing):

=Total Miles Mowing Rural +
Total Miles Mowing Urban

For function 474 (litter barrels):

=Total number of litter barrels

For function 476 (herbicide):

=Total Miles Mowing Rural + Total Miles Mowing Urban

Bridge and Structure Maintenance

For functions 481,486,490-494:

=Total Bridge Length

For functions 483,499:

=Total Number of Bridges

For functions 495-496:

=Total Number of Movable Bridges

For function 487(non-timber foundation service):

=Total Number of Non-timber bridges

For function 485 (concrete deck maintenance):

=Total square feet concrete deck

For function 497 (maintenance of ferry approaches, bridges, and rail crossings by others):

=Total Number of Bridges +
Total Number of Ferries +
Total Number of Rail Crossings

Traffic Services (511-559)

For functions 511,533,534,538,542,559 (snow & ice control, traffic signs, guardrails, etc):

=Total Miles

For functions 528, 531, 539, 540 (pavement striping & reflective tape):

=Total Miles – Total Miles Gravel

For functions 532, 535, 536 (signal devices):

=Number of Signal Devices

For function 556 (sweeping):

=Miles of sweeper curb

Maintenance of Ferry Approaches (434)

=Total Number of Ferry Crossings

These calculations are performed for each function / system / district combination, and the results are stored into an Access table.

Average Unit Accomplishment Costs

Average unit accomplishment costs are calculated for each function, district, and system combination for the latest fiscal year available. The costs are calculated separately for regular time personnel, overtime personnel, equipment, and materials.

The unit cost is calculated by dividing the total cost in each cost category by the total units accomplished. It should be noted that, while excellent records are maintained on costs, the quality of the accomplishment data is suspect. Many WO's had costs with 0 accomplishment units noted. Thus, the accuracy of the unit costs will be affected. To avoid biasing the unit cost upward as a result, only WO's having non-zero accomplishment units are considered in the calculation. The calculated unit cost values can be overwritten by the planner.

Fringe benefit and overhead cost rates are calculated as well but can be overwritten by the planner by specifying a fringe benefit and overhead rate (%).

Predicted Unit Accomplishments Required

In this step, a prediction of the number of accomplishment units required in the next year is calculated. This prediction is based on continuation of the same service level as the previous year (changes in service level are handled in a later step).

Unit Accomplishment Rate (UAR) Model

The UAR model is used to predict the average annual and quarterly number of accomplishment units for each function per maintained unit for that function –i.e., the unit accomplishments rate per maintained unit.

This model is based on a linear regression model of the following form:

$$UAR_{i,q,s} = C_{0,i,q,s} + C_{1,i,q,s}F_1 + C_{2,i,q}F_2 + ... + C_{N,i,q,s}F_N \quad (1)$$

where:

$UAR_{i,q,s}$ = UAR for function i in quarter q

$C_{j,i,q,s}$ = Fit Coefficient j for function i, quarter q. C_o is a baseline coefficient.

F_j = Covariate factor j

The covariate factors are condition-related values and roadway characteristics that might affect the accomplishments rates. The following factors were considered:

- Weighted ADT
- Weighted Total Condition Rating
- Weighted Total Safety Rating
- Weighted Total Rating
- Lane Miles of Each Surface Type
- Lane Miles of Each Pavement Type
- Lane Miles of Each Base Type
- Weighted Lanes
- Weighted Years Since Improved
- Lane Miles Concrete
- Lane Miles Concrete Equivalent 2 Lane
- Lane Miles Asphaltic Concrete Equivalent 2 Lane
- Lane Miles Asphaltic Concrete Equivalent 2 Lane P1200ADT
- Lane Miles Asphaltic Concrete Equivalent 2 Lane M1200ADT
- Lane Miles Composite
- Lane Miles Composite Equivalent 2Lane P1200ADT
- Lane Miles Composite Equivalent 2 Lane M1200ADT
- Lane Miles Asphalt
- Lane Miles Gravel
- Miles Shoulder Nonpaved

- Miles Shoulder Nonpaved Turf
- Miles Shoulder Nonpaved Aggregate
- Miles Shoulder Paved
- Miles Mowing Urban
- Miles Mowing Rural
- Miles Sweeper Curb
- Physical Acres
- Vehicle Miles
- Number Litter Barrels
- Number Rest Areas
- Number Crash Devices

Models were fit and tested for explanatory power using SAS's (a well-known statistical package) stepwise multiple variable regression analysis procedure, with a 95% confidence level. SAS's stepwise regression procedure was used, which not only fits coefficients but also selects which variables to include in the model as most significant.

To make it easier to refit the model, a procedure was developed for automatically producing the necessary SAS data sets and programs, calling SAS to execute the programs, and importing back the model fit results. This procedure assumes that SAS is installed on the same computer. It is also possible to export the data and then separately import the result files if SAS is not available locally.

The DSS program developed (described later in this section) also has a built-in regression procedure to allow the model coefficients to be regularly updated. This procedure is not stepwise, and assumes that all the significant variables identified in the above procedure are included in the predictive model for each block. The procedure then recalculates the coefficients based on a specified year range of data.

Base Function Costs Calculations

In this step, the predicted cost by function in each cost category (regular time, overtime, materials, and equipment), and by quarter, district, and system is calculated. This is simply the multiplication of Units Required * Average Unit Cost, as follows:

$$C_{c,f,q,d,s} = N_{f,d,s} * P_{f,q,d,s} * U_{c,f,d,s} \qquad (2)$$

where:

c = Cost Category (regular time labor, overtime labor, materials, equipment)

f = Function index

q = Fiscal quarter (1 through 4)

d = District

s = System type

$C_{c,f,q,d,s}$ = Base cost c for function f in (q,d,s)

$N_{f,d,s}$ = Maintained units for function f in (d,s)

$P_{f,q,d,s}$ = Predicted Accomplishment Unit Rate for function f in (q,d,s)

$U_{c,f,d,s}$ = Unit cost c for function f in (d,s)

In addition, fringe costs are calculated and stored as well as added to the regular and overtime costs:

$$\begin{aligned} F_{c,f,q,d,s} &= FR * C_{c,f,q,d,s} \\ C_{c,f,q,d,s} &= F_{c,f,q,d,s} + C_{c,f,q,d,s} \end{aligned} \quad (3)$$

where:

FR = State fringe benefit rate

$F_{c,f,q,d,s}$ = Fringe benefits for function f in (q,d,s)

Service Level Model & Calculations

In defining the cost equations in the prior subsections, it is implicitly assumed that historical maintenance service levels are continued into the future. This may not be adequate. Ideally, budget funding should also be a function not only of the predictive factors listed in the prior section, but also of the desired level of service. There are two possible approaches to this problem:

- **Empirical Estimation**. Equations are fit to model the predicted effects on each service objective (or combined measure) at different levels of maintenance effort (cost). This is the approach that the LA DOTD PAVE system ultimately hopes to achieve. Generally, accurate data collected in abundance under controlled testing conditions is needed to develop acceptable models. Specific objective measures must be defined and regularly assessed.

- **Subjective Estimation**. In the absence of sufficient quality data, subjective methods can be used to characterize the relationship between maintenance effort and service level provided.

Because of the absence of controlled historical data, the latter approach is utilized in this methodology:

- Condition data in NEEDS is not updated on an annual basis, and may be at least somewhat dated for many road sections.

- The impact of dollars spent on routine maintenance functions on pavement life, safety, and user satisfaction is not characterized. Even the impact on expenditures indirect measures (such as safety rating) is not available.

- Unlike a controlled experiment, past effort levels in the districts were not "scientifically" controlled. As a result, differences in objective measures may be due to differences in maintenance effectiveness among districts/systems rather than maintenance dollar support level.

- Maintenance effort levels are fairly standardized between and within locations. As a result, there is not a great range of maintenance effort levels on which to fit an equation.

An attempt was made earlier in this study to isolate service level effects. A sophisticated model was fit using regression analysis that attempted to isolate the effect of differences in maintenance expenditures between control sections with similar characteristics (system, ADT, surface/pavement/base type, and safety/condition ratings) on subsequent condition and safety rating. However, as a result of the issues discussed above, the resulting model was statistically weak and did not provide any significant value in predicting the relationship between expenditures and service levels achieved.

In the absence of suitable historical data for developing a model, a subjective model has been developed. Actual data was not collected from LA DOTD personnel for fitting the model; however, the mechanism for collecting, fitting, and utilizing the data has been built into the budget planning DSS. This is described in the following paragraphs.

To collect the service level data, district and area supervisors would be asked to indicate how much effort (as a % of the previous year's effort) would be required to provide 1) a "good" level of service, and 2) a "minimum" adequate level of service for each function / system combination. These would then be multiplied by the previous year's unit accomplishment rates. The results would then be averaged within each district to get a 90th ("good") and 10th ("minimum adequate") percentile unit accomplishment rate estimate respectively for each district / function / system combination. A linear function is assumed for the relation between service level and unit accomplishment rate. Based on this, the service rate for the previous year for each district / function / system combination is calculated and stored as well.

Service level input data may be entered directly into the DSS by form, or imported from a text file, Excel spreadsheet, or Access database table.

In specifying future desired service levels, the following linguistic terms, their basic intention, and associated service level (on a scale from 0 to 1) is used:

Table 1: Service level terms

Linguistic Term	Meaning	Service Level
Inadequate	Not being serviced at the minimum level required to keep roadways in service, provide basic services, or avoid liability due to negligence	0.0
Minimum	Minimum service levels required to keep roadways in service; provide basic service for ferries, tolls, or rest areas; and avoid liability due to negligence.	0.25
Satisfactory	Sufficient to keep roadway in good condition and general user satisfaction.	0.5
Good	Sufficient to maintain or extend roadway life and/or maintain high user satisfaction levels.	0.75
Excellent	Highest reasonable level of effective service.	1.0

Fringe, Overhead, & Total Cost Calculations

After application of the service level adjustment, fringe and overhead costs are calculated (and stored) and applied to the adjusted base costs to arrive at total costs by function, district, system, and quarter:

$$O_{f,q,d,s} = OR * \sum_{\forall c} C_{c,f,q,d,s}$$
$$TC_{f,q,d,s} = O_{f,q,d,s} + \sum_{\forall c} C_{c,f,q,d,s} \quad (4)$$

where:

c = Cost Category (regular time labor, overtime labor, materials, equipment)

f = Function index

q = Fiscal quarter (1..4)

d = District

s = System type

$C_{c,f,q,d,s}$ = Base cost c for function f in (q,d,s)

OR = State overhead rate (as a %)

$O_{f,q,d,s}$ = Overhead cost for function f in (q,d,s)

$TC_{f,q,d,s}$ = Total cost (including overhead) of function f in (q,d,s)

In addition, the following aggregations are also calculated and stored for planning purposes:

- Sum of total costs by function, quarter, and district
- Sum of total costs by quarter and district
- Sum of total costs by function and district
- Sum of total costs by function
- Sum of total costs by district (the total district routine maintenance budget)
- Sum of total costs (the total state routine maintenance budget)

Function Prioritization Model

To make effective decisions on allocation of limited maintenance funds to maintenance functions, it is necessary to have some form of prioritization scheme in place.

The primary objectives of any maintenance organization include:

- **Safety.** Maintenance should be performed to keep roads clear of large faults, bumps, ruts, debris, and so forth, that might cause safety hazards during normal operation and during accidents

- **Preservation of Assets.** Application of preventive maintenance can slow / prevent deterioration of function of pavement, structures, drain systems, etc.

- **User Satisfaction.** For pavement, right-of-way, and structure maintenance this can be divided into:

  - *Ride Quality Perception.* Perceived ride comfort, for all user classes.

  - *Aesthetics.* Visual perception of pavement, structures, right of way.

  For toll services, satisfaction is primarily measured on *service time.* For ferry crossings, satisfaction is primarily based on the *number of crossing* made daily.

Different priorities (weightings) may be assigned to these objectives. Furthermore, these priorities may differ across function classes (systems) and districts.

This work did not include a study to determine LA DOTD's actual function priorities. However, it did build in the mechanism for collecting this data and incorporating it into the budget-planning model.

It is assumed that a survey is conducted of district and area supervisors, and transportation engineers to determine the function priorities. Each participant would first be asked to perform a forced ranking (1-5) of the importance of each objective for each system within his or her district:

- Safety
- Preservation of Assets
- Ride Quality
- Aesthetics
- Service (tolls, ferries, rest areas)

This information would be tabulated into a file or table format similar to the following

Table 2: Objective rankings format

District	ParticipantID	System	Objective	Rank
1	1	1	1	1
1	1	1	2	3
1	1	1	3	2
1	1	1	4	4
1	1	1	5	5
1	2	1	1	2
etc...				

The participants would then be asked to provide a ranking on a scale of "Very Effective" (3), "Moderately Effective" (2), or "Little or No Impact" (1) for each function towards meeting each objective. The participant need only identify those functions with particularly high (or low) effectiveness relative to other functions – a blanket rank can be assigned to all other functions using the function number "0." This information would then be tabulated into a file or table format similar to the following:

Table 3: Function effectiveness rankings format

District	ParticipantID	Objective	System	Function	Rating
1	1	1	1	411	3
1	1	1	1	412	1
1	1	1	1	0	2
1	1	2	1	528	3
1	1	2	1	534	3
1	1	2	1	0	1
etc...					

This data may be entered directly into the DSS in the formats indicated above, or imported from a text file, spreadsheet, or Access database table. The following process is used to summarize the ranking into priority weightings for each function / district / system combination.

1. The data file is read in. For each participant, any objective/function/district/system combination not specifically ranked is assigned either the blanket ranking, or if no blanket rating is defined, a rating of 1 is assigned.

2. The average objective ranking, $O_{o,d,s}$, is calculated for each objective / district / system combination. The average function effectiveness ranking, $R_{o,f,d,s}$, is calculated for each objective / function / district / system combination.

3. A priority weight for each function / district / system combination is calculated as follows:

$$W_{f,d,s} = \sum_{o} O_{o,d,s} * R_{o,f,d,s} \tag{5}$$

   where:

   o = objective o (safety, preservation, ride, aesthetics, service)

   $W_{f,d,s}$ = priority weighting for function f, system s, in district s

   $O_{o,d,s}$ = ranking of objective o overall for system s in district d

   $R_{o,f,d,s}$ = ranking of effectiveness towards objective o for system s in district d

4. Priority weights are then normalized on districts to ensure that districts don't give high priorities to all functions to insure a higher budget allocation:

$$W_{f,d,s} = \frac{W_{f,d,s}}{\sum_{f,s} W_{f,d,s}} \tag{6}$$

5. Finally, all priority weights are normalized to a total range of 1 to 10 in order to ensure against scaling problems in the allocation optimization model:

$$W_{f,d,s} = 1 + 9 * \frac{W_{f,d,s}}{\sum_{f,d,s} W_{f,d,s}} \qquad (7)$$

Allocation Model

The basic cost model developed previously will give us an accurate projection of maintenance costs given that maintenance effort levels remain consistent and budget limitations are not present. However, the planning process usually demands some level of "what-if" analysis. To this end, an optimization model was developed and integrated into the DSS to assist planners in this analysis. The model can be used in three ways:

- *Constrained Budget, Unconstrained Service Levels.* In this case, a fixed total maximum annual maintenance budget is specified as a constraint, and the model seeks to allocate funds so as to maximize the prioritized aggregate service levels.

- *Constrained Budget & Service Levels.* In this case, the minimum required service level is specified for some or all functions, in addition to the budget constraint. The model seeks to allocate funds so as to maximize the prioritized aggregate service levels while meeting the minimum service level requirements specified.

- *Constrained Service Levels, Unconstrained Budget.* In this case, required service levels are specified for all functions. The model calculates the total cost to meet the service level requirements.

The basic optimization model is as follows. The objective is to maximize the priority weighted (function/district/system priorities $W_{f,d,s}$) aggregate service level WSL:

$$\text{Max} \quad WSL = \sum_{f,d,s} W_{f,d,s} * SL_{f,d,s} \qquad (8)$$

Subject to the following constraints:

1) Constraint on Budget (B)

$$\sum_{f,q,d,s} TC_{f,q,d,s}(SL_{f,d,s}) \leq B \qquad (9)$$

2) Service Level limits

$$0 \leq SL_{f,d,s} \leq 1 \quad \forall \ f,d,s \qquad (10)$$

The above model is guaranteed to have a solution for non-negative budget B.

Minimum required service level constraints may be added for one or more functions to the previous model. These constraints take the form of:

$$SL_{f,d,s} \geq MinSL_{f,d,s} \tag{11}$$

for each (f,d,s) combination for which a minimum requirements is specified. Note that it is possible in this case that the model may not have a feasible solution.

The optimization model as described is a nonlinear model, since total cost is a nonlinear function of service level. LINGO (a well-known general optimization package) dynamic link library (DLL) optimization functions were utilized in the decision support system (DSS) to solve the models. The DSS formulates the model structure and coefficient values in text format. The model is then passed to LINGO's optimization engine through function calls to the LINGO DLL library. Model solutions (variable and objective function values) are returned through library function calls as vector variables.

Budget planners may also be interested in how much money would be required to meet target service levels in all functions. In this case, the budget constraint is removed, and the inequality in the above service level constraints is replaced with equality conditions:

$$SL_{f,d,s} = MinSL_{f,d,s} \quad \forall \ f,d,s \tag{12}$$

In this case, the model is no longer one of optimization but of constraint satisfaction. Costs are calculated directly by using the MinSL values in the total cost functions, and the optimization process is bypassed.

DECISION SUPPORT SYSTEM (DSS) DESIGN & IMPLEMENTATION

A decision support system (DSS) was developed in Access 2000 to implement the previously discussed models. Visual Basic for Applications (VBA) and Structured Query Language (SQL) were used as the primary mechanisms for implementing model logic. The underlying table design is shown in Figure 1.

BaseData_NEEDS		
PK,I1	**ID**	COUNTER
	District	INTEGER
	Parish	INTEGER
	System	INTEGER
	ControlSection	VARCHAR(6)
	Length	DOUBLE
	ADT	INTEGER
	TotalConditionRating	SMALLINT
	TotalSafetyRating	SMALLINT
	TotalRating	SMALLINT
	SurfaceType	INTEGER
	PavementType	INTEGER
	BaseType	INTEGER
	LastYearImproved	SMALLINT
	YearsSinceImproved	INTEGER
	Lanes	SMALLINT

BaseData_ObjectiveRankings		
PK	**District**	INTEGER
PK,I1	**ParticipantID**	INTEGER
PK	**System**	INTEGER
PK	**Objective**	INTEGER
	Rank	REAL

BaseData_Function		
PK	**Function**	INTEGER
	FunctionName	VARCHAR(40)
	AccomplishmentUnits	VARCHAR(30)

BaseData_Districts		
PK	**District**	INTEGER
	Description	VARCHAR(255)

BaseData_FerryCrossings		
PK,I1	**FerryCrossingID**	COUNTER
	District	VARCHAR(50)
	FerryCrossingDesc	VARCHAR(50)

BaseData_Systems		
PK	**System**	INTEGER
I2	SystemName	VARCHAR(50)
I3	PopulationType	VARCHAR(50)
I1	Description	VARCHAR(100)

BaseData_RailCrossings		
PK,I1	**RailCrossingID**	COUNTER
	District	INTEGER
	ADT	DOUBLE
	ConditionRating	DOUBLE
	CrossingDescription	VARCHAR(50)

BaseData_Parishes		
PK	**ParishNumber**	INTEGER
I1	ParishName	VARCHAR(17)

BaseData_MOPS_WorkOrders		
PK	**Function**	INTEGER
PK	**District**	INTEGER
PK	**FiscalYear**	INTEGER
PK	**Parish**	INTEGER
PK	**Quarter**	INTEGER
PK	**ControlSection**	VARCHAR(50)
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE

BaseData_FunctionEffectivenessRankings		
PK	**District**	INTEGER
PK,I1	**ParticipantID**	INTEGER
PK	**System**	INTEGER
PK	**Objective**	INTEGER
PK	**Function**	INTEGER
	Rank	DOUBLE

BaseData_Tolls		
PK,I1	**TollID**	COUNTER
	District	INTEGER
	System	INTEGER
	TollDesc	VARCHAR(100)

BaseData_TrafficDevices		
PK,I1	**DeviceID**	COUNTER
	District	INTEGER
	System	INTEGER
	DeviceType	INTEGER

Figure 1 (a): Database table design – base data tables

SummaryData_DistrictFunctionLevel		
PK	Function	INTEGER
PK	District	INTEGER
PK	System	INTEGER
PK	FiscalYear	INTEGER
PK	Quarter	INTEGER
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE

SummaryData_DistrictLevel		
PK	District	INTEGER
PK	System	INTEGER
I7	NumberTolls	INTEGER
I5	NumberSignalDevices	INTEGER
I4	NumberRailroadCrossings	INTEGER
I1	NumberBridges	INTEGER
I3	NumberNonTimberBridges	INTEGER
I6	NumberTimberPileBridges	INTEGER
I2	NumberMovableBridges	INTEGER
	BridgeLength	DOUBLE
	SquareFeetConcreteDeck	DOUBLE
	Length	DOUBLE
	MilesConcrete	DOUBLE
	MilesConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneP1200ADT	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneM1200ADT	DOUBLE
	MilesComposite	DOUBLE
	MilesCompositeEquivalent2LaneP1200ADT	DOUBLE
	MilesCompositeEquivalent2LaneM1200ADT	DOUBLE
	MilesAsphalt	DOUBLE
	MilesGravel	DOUBLE
	MilesShoulderNonpavedTurf	DOUBLE
	MilesShoulderNonpavedAggregate	DOUBLE
	MilesShoulderPaved	DOUBLE
	MilesMowingUrban	DOUBLE
	MilesMowingRural	DOUBLE
	MilesSweeperCurb	DOUBLE
	PhysicalAcres	DOUBLE
	VehicleMiles	DOUBLE
	NumberLitterBarrels	INTEGER
	NumberRestAreas	INTEGER
	NumberCrashDevices	INTEGER

BaseData_MOPS_Inventory		
I2	District	INTEGER
I3	Gang	VARCHAR(3)
I7	System	INTEGER
I1	Control	VARCHAR(3)
I6	Section	VARCHAR(2)
I5	Parish	INTEGER
I4	Loc-District	VARCHAR(2)
	Length	DOUBLE
	MilesConcrete	DOUBLE
	MilesConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneP1200ADT	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneM1200ADT	DOUBLE
	MilesComposite	DOUBLE
	MilesCompositeEquivalent2LaneP1200ADT	DOUBLE
	MilesCompositeEquivalent2LaneM1200ADT	DOUBLE
	MilesAsphalt	DOUBLE
	MilesGravel	DOUBLE
	MilesShoulderNonpavedTurf	DOUBLE
	MilesShoulderNonpavedAggregate	DOUBLE
	MilesShoulderPaved	DOUBLE
	MilesMowingUrban	DOUBLE
	MilesMowingRural	DOUBLE
	MilesSweeperCurb	DOUBLE
	PhysicalAcres	DOUBLE
	VehicleMiles	DOUBLE
	NumberLitterBarrels	INTEGER
	NumberRestAreas	INTEGER
	NumberCrashDevices	INTEGER

SummaryData_ControlSectionFunctionLevel		
PK	District	INTEGER
PK	Parish	INTEGER
PK	System	INTEGER
PK	ControlSection	VARCHAR(6)
PK	Function	DOUBLE
PK	FiscalYear	INTEGER
PK	Quarter	INTEGER
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE
	ManhoursRegularTimeNonzeroUnits	DOUBLE
	ManhoursOvertimeNonzeroUnits	DOUBLE
	PersonnelCostNonzeroUnits	DOUBLE
	EquipmentCostNonzeroUnits	DOUBLE
	MaterialCostNonzeroUnits	DOUBLE

SummaryData_ControlSectionLevel		
PK	District	INTEGER
PK	Parish	INTEGER
PK	System	INTEGER
PK	ControlSection	VARCHAR(6)
	Length	DOUBLE
	WeightedADT	DOUBLE
	WeightedTotalConditionRating	DOUBLE
	WeightedTotalSafetyRating	DOUBLE
	WeightedTotalRating	DOUBLE
	MilesSurfaceType1	DOUBLE
	MilesSurfaceType2	DOUBLE
	MilesSurfaceType3	DOUBLE
	MilesSurfaceType4	DOUBLE
	MilesSurfaceType5	DOUBLE
	MilesSurfaceType6	DOUBLE
	MilesSurfaceType7	DOUBLE
	MilesPavementType1	DOUBLE
	MilesPavementType2	DOUBLE
	MilesPavementType3	DOUBLE
	MilesPavementType4	DOUBLE
	MilesPavementType5	DOUBLE
	MilesPavementType6	DOUBLE
	MilesPavementType7	DOUBLE
	MilesBaseType1	DOUBLE
	MilesBaseType2	DOUBLE
	MilesBaseType3	DOUBLE
	MilesBaseType4	DOUBLE
	MilesBaseType5	DOUBLE
	MilesBaseType6	DOUBLE
	MilesBaseType7	DOUBLE
	WeightedYearsSinceImproved	DOUBLE
	WeightedLanes	DOUBLE

BaseData_Bridges		
PK,I1	BridgeID	COUNTER
	District	INTEGER
	PierType	INTEGER
	Movable	BIT
	Length	DOUBLE
	ADT	DOUBLE
	ConditionRating	DOUBLE
	TotalSquareFeetConcreteDeck	DOUBLE
	Description	VARCHAR(50)

SummaryData_AvgObjectiveRankings		
	District	INTEGER
	System	INTEGER
	Objective	INTEGER
	Rank	DOUBLE

SummaryData_AvgFunctionEffectivenessRankings		
PK	District	INTEGER
PK	System	INTEGER
PK	Objective	INTEGER
PK	Function	INTEGER
	Rank	DOUBLE

SummaryData_PriorityWeightings		
PK	District	INTEGER
PK	System	INTEGER
PK	Function	INTEGER
	Weight	DOUBLE

Figure 1 (b): Database table design – base data tables

ServiceLevels_FerryCrossings		
PK,I6	**FerryCrossingID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I5	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I4	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfPilots	INTEGER
	AvgPilotPay	DOUBLE
I2	NumberOfStaff	INTEGER
	AvgStaffPay	DOUBLE
I3	NumberOfTrips	INTEGER
	FuelCostPerTrip	DOUBLE

ServiceLevels_Restareas		
PK,I5	**RestareaID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I4	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I3	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfJanitorialStaff	INTEGER
	AvgJanitorialPay	DOUBLE
I2	NumberOfSecurityStaff	INTEGER
	AvgSecurityStaffPay	DOUBLE

ServiceLevels_Tolls		
PK,I5	**TollID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I4	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I3	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfCollectors	INTEGER
	AvgCollectorPay	DOUBLE
I2	NumberOfSecurityStaff	INTEGER
	AvgSecurityStaffPay	DOUBLE

ServiceLevels_Functions		
PK	**Function**	**INTEGER**
PK	**District**	**INTEGER**
PK	**System**	**INTEGER**
	ServiceLevel	VARCHAR(50)

UAR_Variables		
PK,I1	**Variable**	**COUNTER**
U1	VariableName	VARCHAR(100)
	Source	VARCHAR(50)
	FieldName	VARCHAR(100)
	SASname	VARCHAR(100)
	Description	LONGCHAR

UAR_ModelCoefficients		
PK	**District**	**INTEGER**
PK	**Quarter**	**INTEGER**
PK	**System**	**INTEGER**
PK	**Function**	**INTEGER**
PK	**Variable**	**INTEGER**
	UAR_Coefficient	DOUBLE
	Rsquared	DOUBLE
	ChiSquare	DOUBLE

UAR_FunctionVariableMap		
I2	VariableName	VARCHAR(100)
I1	FunctionCode	INTEGER
	State	INTEGER
	OrdinalValue	INTEGER

Figure 1 (c): Database table design – service level and UAR tables

Budget_ScenarioDetails

PK,I1	ScenarioID	INTEGER
PK	District	INTEGER
PK	Quarter	INTEGER
PK	System	INTEGER
PK	Function	INTEGER
	Budget	DOUBLE

SASConfig

	DatabasePath	VARCHAR(255)
	WorkGroupPath	VARCHAR(255)
	SASInputFilePath	VARCHAR(255)
	SASAppPath	VARCHAR(255)

Budget_Scenario

PK,I1	ScenarioID	INTEGER
	BudgetYear	INTEGER
	Description	VARCHAR(50)

SASRunInfo

PK	Function	INTEGER
PK	District	INTEGER
PK	Parish	INTEGER
PK	System	INTEGER
PK	Quarter	INTEGER
PK	DV	INTEGER
	ParamTable	VARCHAR(50)
	CoefTable	VARCHAR(50)

Rates

	FringeBenefitsRate	DOUBLE
	OverheadRate	DOUBLE

Import

PK	DestinationTable	VARCHAR(50)
	ImportName	VARCHAR(50)
	ImportDescription	VARCHAR(100)
	ImportFilePath	VARCHAR(255)
	SourceTable	VARCHAR(50)
	SourceType	VARCHAR(50)
	DeleteOldFirst	BIT

ImportDetails

PK,FK1,I2,I1	DestinationTable	VARCHAR(50)
PK	DestinationField	VARCHAR(50)
	DestinationFieldType	VARCHAR(50)
	StartPosition	INTEGER
	FieldLength	INTEGER

Figure 1 (d): Database table design – budget, SAS, and import tables

Startup

On startup of the DSS, the following splash screen (Figure 3) is displayed.

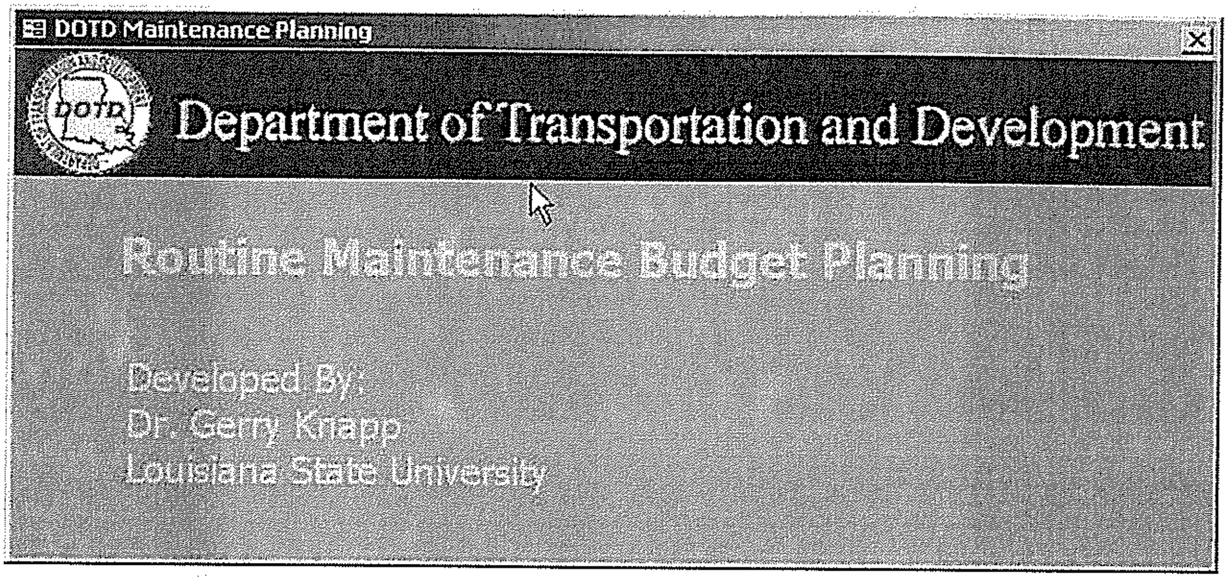


Figure 2: Splash screen

The splash screen closes automatically within 3 seconds. The planner is then presented with the following menu system (Figure 3-9)

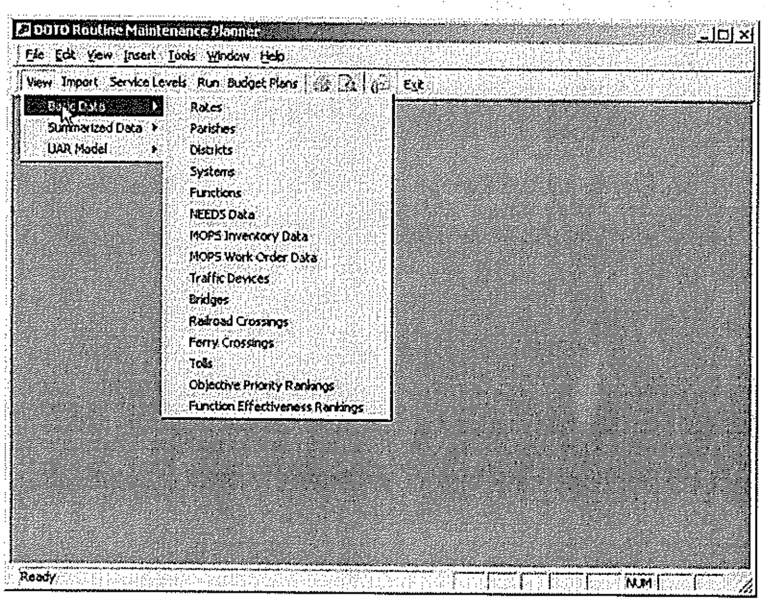


Figure 3: Menu system – view base data

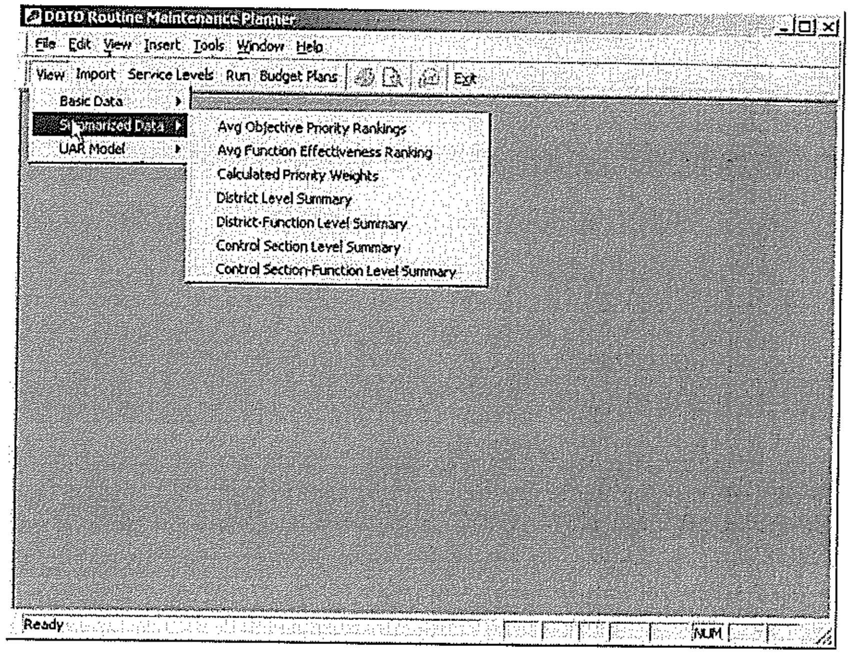


Figure 4: Menu system – view summary data

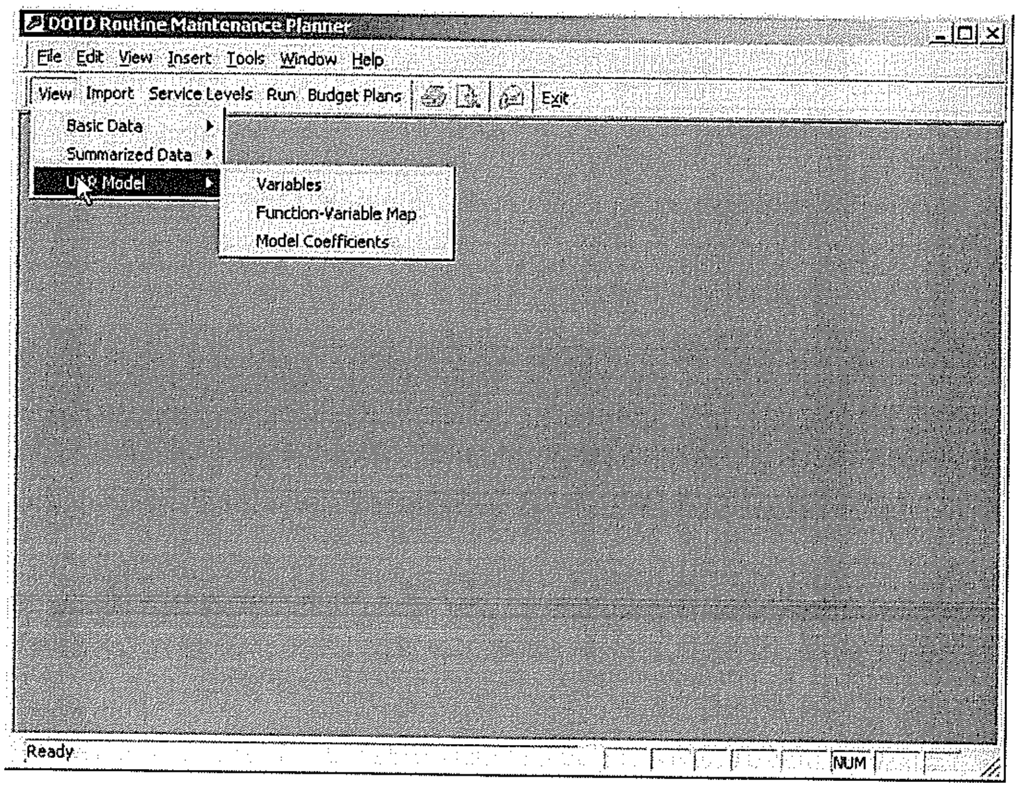


Figure 5: Menu system – view unit model data

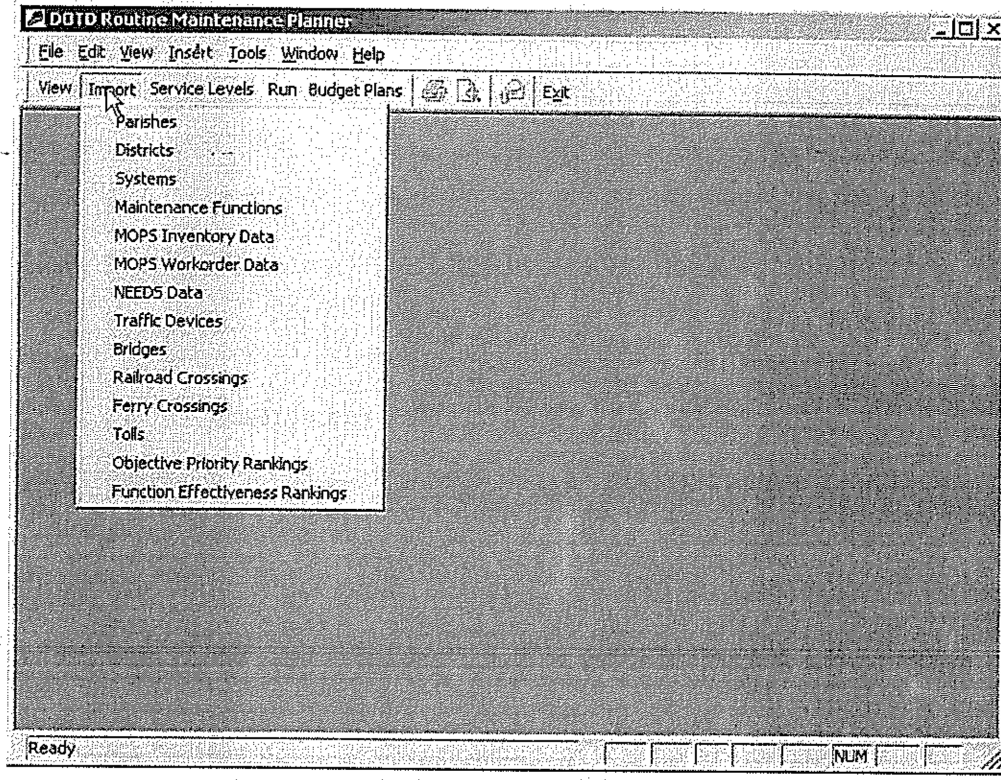


Figure 6: Menu system – import options

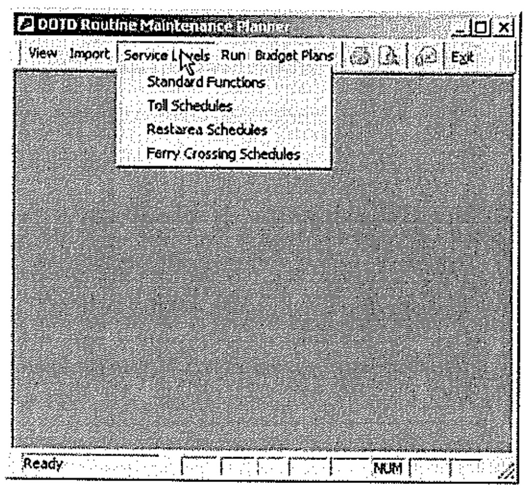


Figure 7: Menu system – service level settings

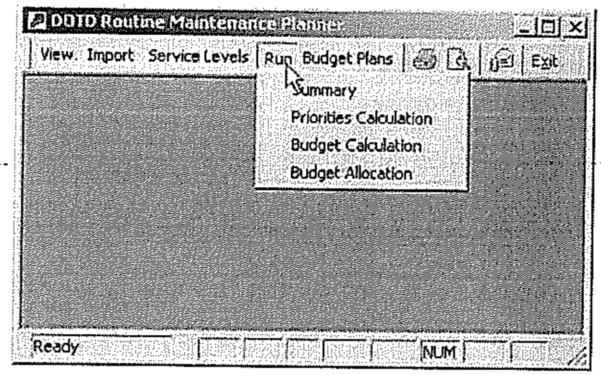


Figure 8 : Menu system - run options

View Menu

Basic information on parishes, districts, and maintenance functions can be viewed and edited by selecting the corresponding option from the menu. The corresponding forms are shown in Figures 10-12.

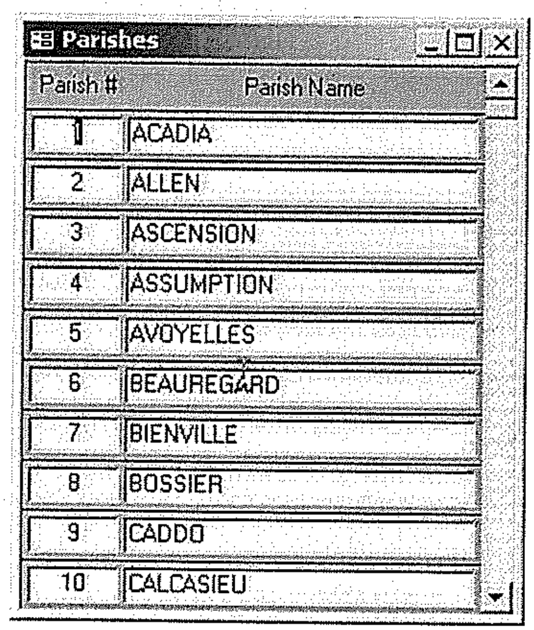
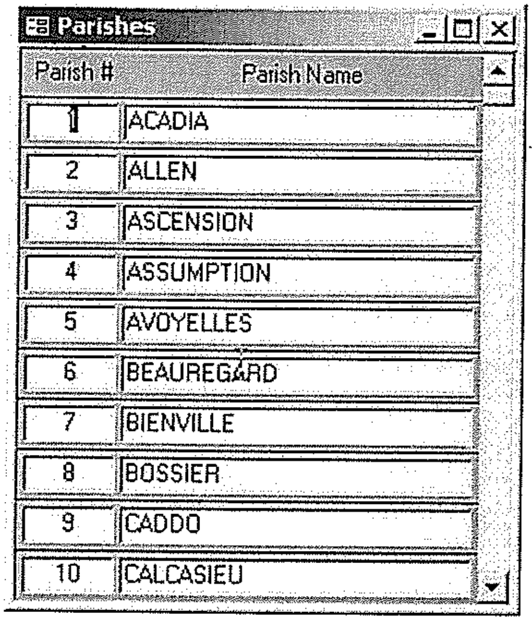
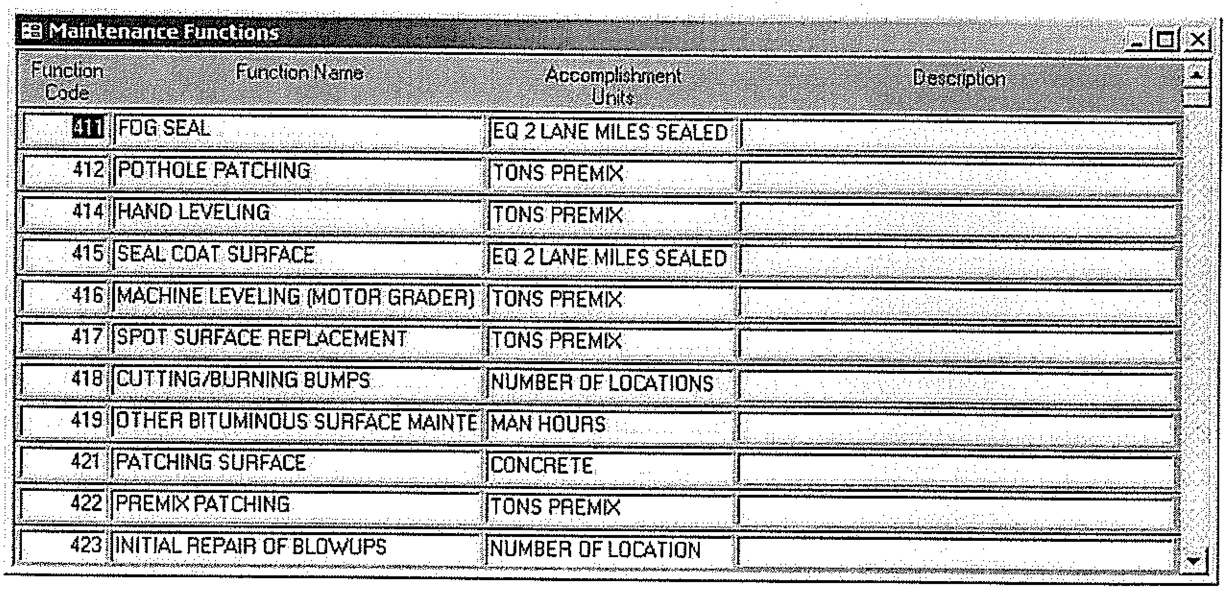


Figure 9: Parishes form



Parish #	Parish Name
1	ACADIA
2	ALLEN
3	ASCENSION
4	ASSUMPTION
5	AVOYELLES
6	BEAUREGARD
7	BIENVILLE
8	BOSSIER
9	CADDO
10	CALCASIEU

Figure 10: Districts form



Function Code	Function Name	Accomplishment Units	Description
411	FOG SEAL	EQ 2 LANE MILES SEALED	
412	POTHOLE PATCHING	TONS PREMIX	
414	HAND LEVELING	TONS PREMIX	
415	SEAL COAT SURFACE	EQ 2 LANE MILES SEALED	
416	MACHINE LEVELING (MOTOR GRADER)	TONS PREMIX	
417	SPOT SURFACE REPLACEMENT	TONS PREMIX	
418	CUTTING/BURNING BUMPS	NUMBER OF LOCATIONS	
419	OTHER BITUMINOUS SURFACE MAINTE	MAN HOURS	
421	PATCHING SURFACE	CONCRETE	
422	PREMIX PATCHING	TONS PREMIX	
423	INITIAL REPAIR OF BLOWUPS	NUMBER OF LOCATION	

Figure 11: Maintenance functions form

Imports Menu

Selecting imports from the menu brings up a submenu where you can select what data to import. Once the import type is selected, an import form will come up with the import specification. The form allows the user to enter the format once and have the information saved. Figure 8 shows an example of a text file import specification. Figure 9 shows an example of a database import specification. The import form also supports importing from

Excel spreadsheets. For databases and spreadsheets, the table or sheet must match column for column with the destination table.

The following base data items can be imported:

- Maintenance Functions
- Parishes
- Districts
- Systems
- Needs
- MOPS Work Orders
- MOPS Inventory
- Structures
- Traffic Devices
- Tolls
- Ferry Crossings
- Objective Priority Rankings
- Function Effectiveness Rankings
- SAS Stepwise Regression Results

On import, any prior data will either be overwritten/appended-to or deleted, depending on whether the delete option is unchecked or checked respectively. When the delete option is off, new data that matches an old record will overwrite the old record, otherwise it will be added as a new record.

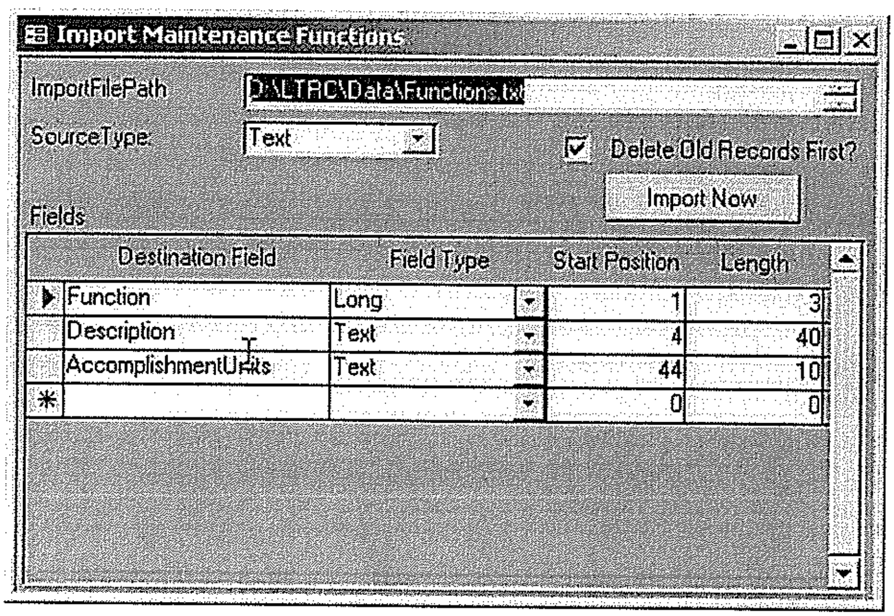


Figure 12: Import form – text file specification

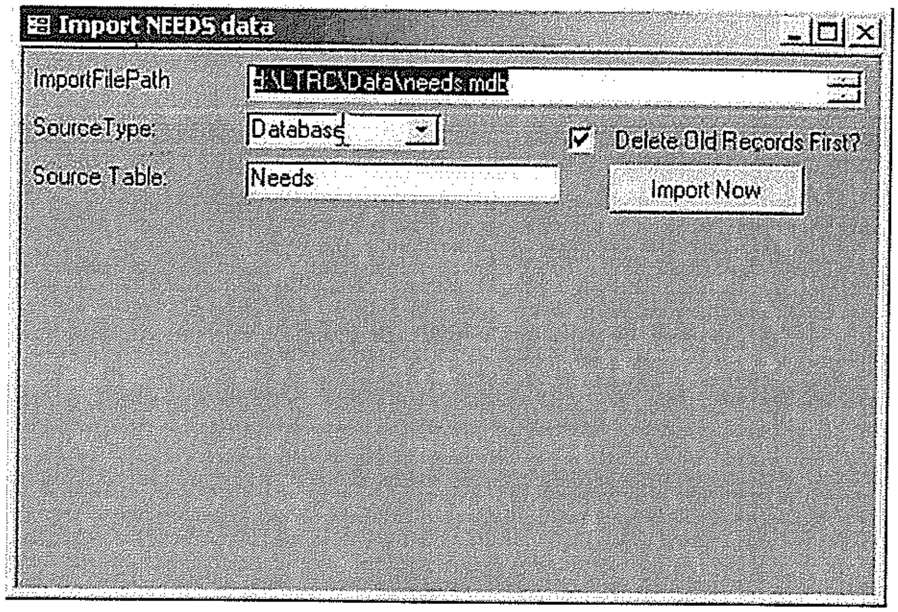


Figure 13: Import form – database table specification

Service Levels Menu

The service levels menu gives the user the ability to create and revise multiple service level scenarios in each of the following categories:

- *Standard functions*. Define service level scenarios for all functions whose service level is not defined in terms of employee schedules.

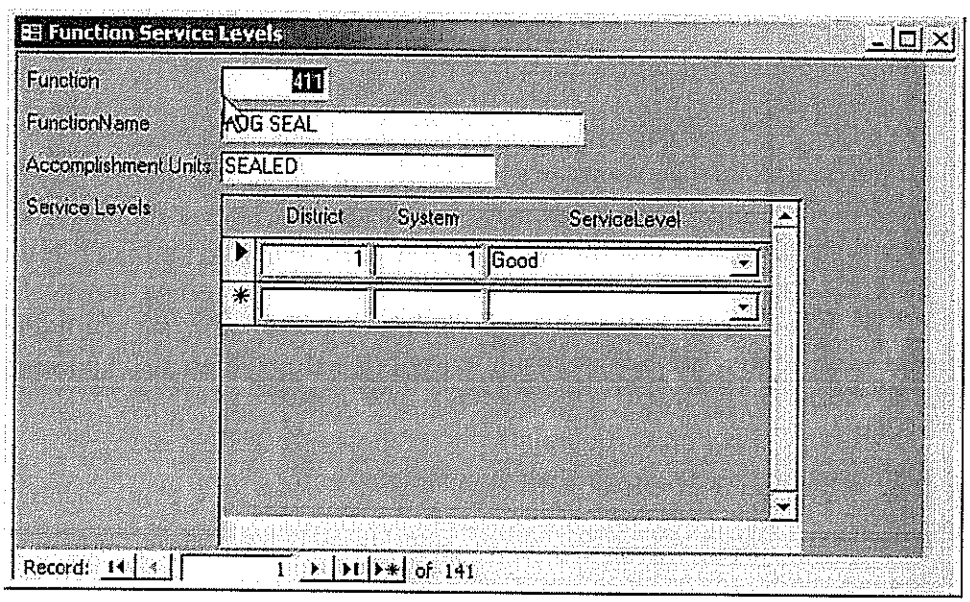


Figure 14: Function service levels form

- *Ferry Crossing Schedules.* Define staffing level scenarios for ferry crossings

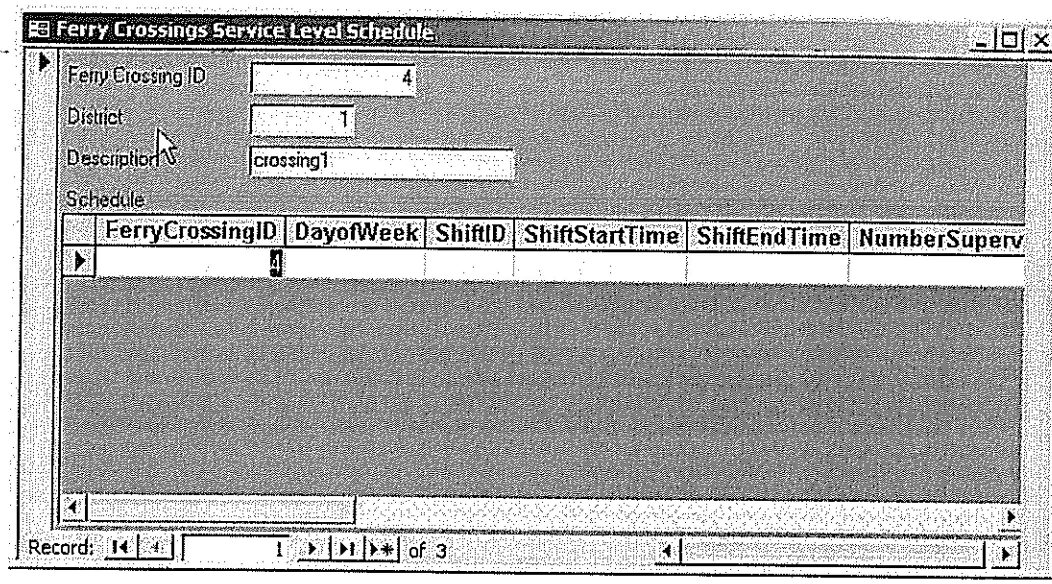


Figure 15: Ferry crossings service level form

- *Toll Schedules.* Define staffing level scenarios for tolls. The form format is similar to that for ferry crossings.

- *Rest area Schedules.* Define staffing level scenarios for rest areas. The form format is similar to that for ferry crossings.

Run Menu

The run menu provides the following sub items:

- *Summarize.* The summarize command is used to run data summaries and integration on all base data. The summaries calculated are discussed under "Data Collection" in this section. Any previous summary is first cleared. Before running this command, the user should be sure that all base data has been imported and is up to date; otherwise, an error might be generated or the summary might reflect out of date values. A message is displayed when it has completed, or if an error is encountered. The district level and control section level summary forms are both opened up as well for review.

- *Priorities Calculation.* Calculates the function/district/system priority weights, and displays the priority weights when completed.

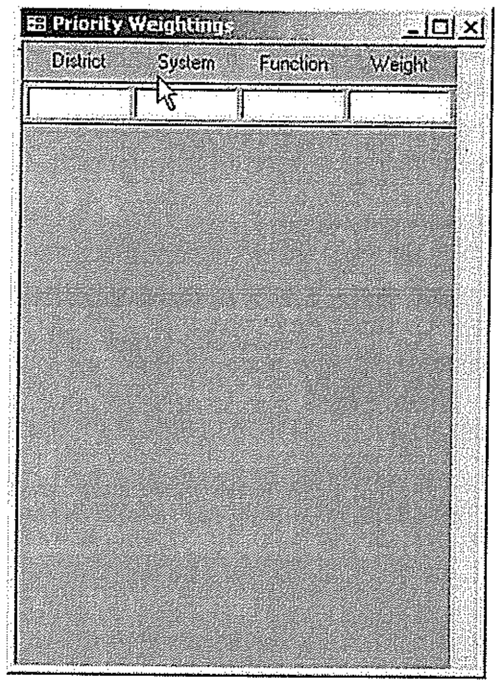


Figure 16: Priority weightings

- *Budget Calculation.* Calculates the budget plan for a specified service level scenario. Assumes budget is unconstrained.

- *Budget Allocation.* Runs the allocation optimization model for a specified service level scenario and budget constraint.

- *Fit Unit Accomplishment Rates.* Performs linear regression analysis across a specified date range to recalculate the unit accomplishment prediction model coefficients. displays the unit accomplishments rates summary form when completed.

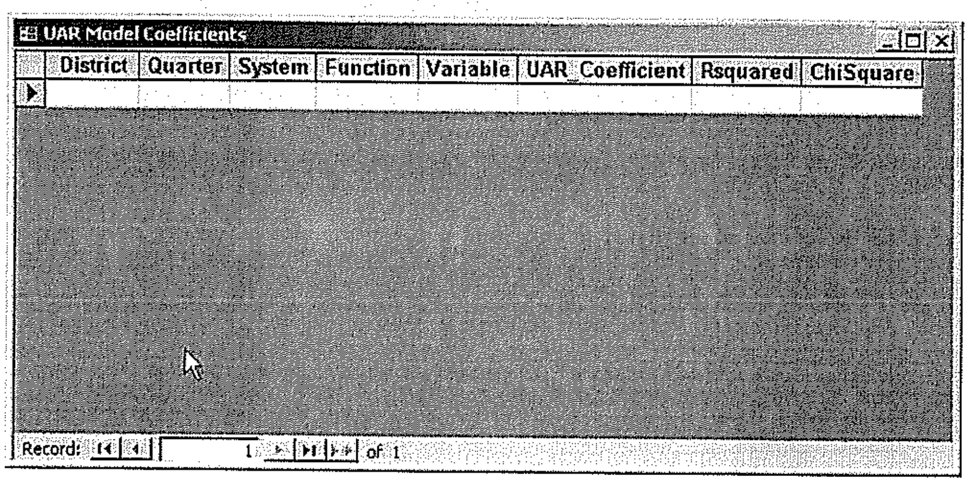


Figure 17: UAR model coefficients form

- *Run SAS Stepwise Regression Model.* Displays the SAS configuration Form. "Run" outputs data in a SAS program format for running the SAS stepwise regression model to select variables for the unit accomplishment rates model, calls SAS to execute the model (this assumes SAS is installed on the same machine), and loads in the resulting unit accomplishment rates (note: this replaces the existing model).

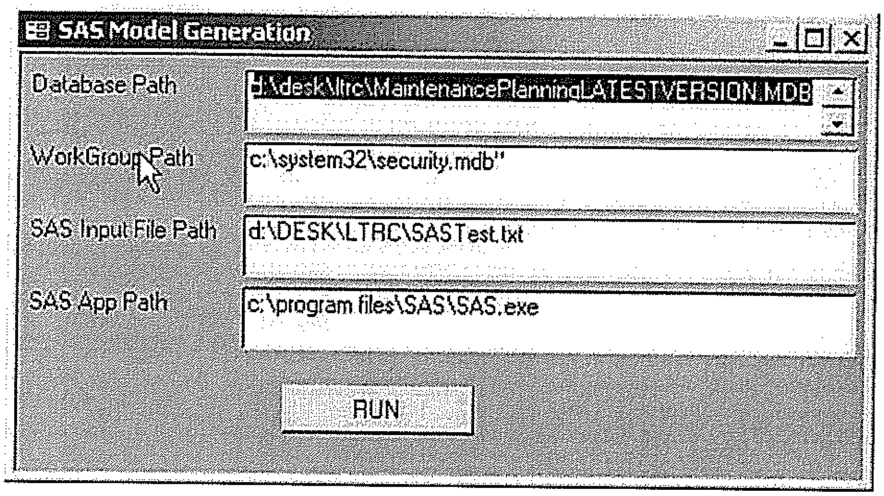


Figure 18: SAS model generation form

Budget Plans

The budget plans menu item allows the user to review previously calculated and stored budget plans. This provides an opportunity to do what-if type analyses and compare the results.

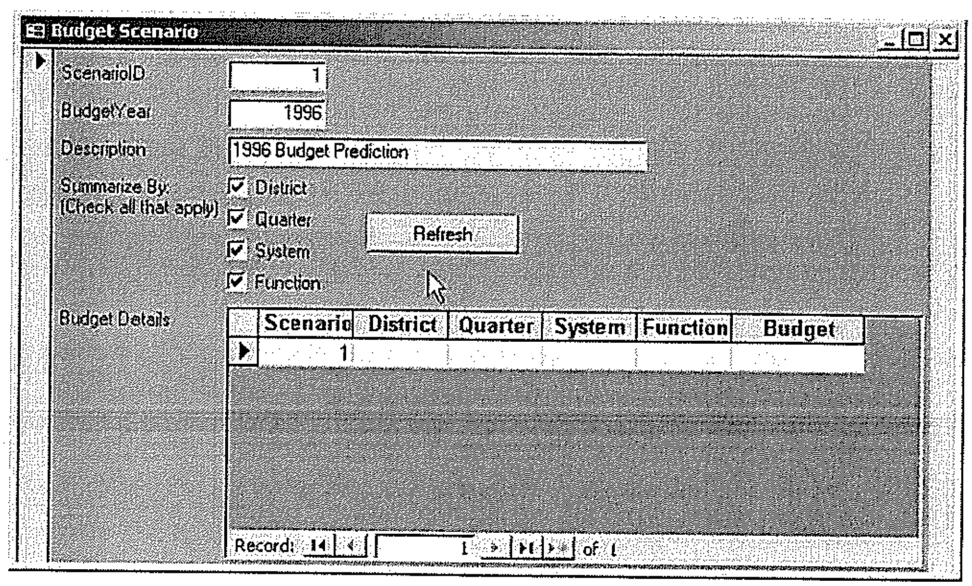


Figure 19: Budget scenarios form

Other Menu Items

Menu options for printing, print preview, emailing, and exiting are also provided on the main menu.

Validation

To test the robustness of the DSS, the following test cases were used:

Table 4: Test cases

CASE	MODEL FIT TO	YEAR PREDICTED	OTHER ASSUMPTIONS
1	1998 Fiscal Year (for AUA) 1997-98 FY (for UAR)	1999 Fiscal Year	2.5% inflation (labor, materials, and equipment). All functions had equal priorities. Service levels same as prior year.
2	1999 Fiscal Year (for AUA) 1998-99 FY (for UAR)	2000 Fiscal Year	Same as case 1

It should be noted that we did not have the exact inventory and NEEDS data available during these fiscal years (we had this data for 1995 and 2001 only). Differences between 1995 and 2001 were interpolated to the respective years being fit/predicted.

For each case the AUA and UAR models were fit to the fiscal years indicated. A prediction was then calculated and compared in total and by quarter, district, and system, against the actual budget incurred in the predicted fiscal year.

The model produced reasonable results, with an average error of 5.3% (low) over the two test cases.

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LOUISIANA DOTD MAINTENANCE BUDGET ALLOCATION SYSTEM

FINAL REPORT

by

GERALD KNAPP
Fred B. and Ruth B. Zigler Associate Professor of Engineering

LAWRENCE MANN, JR.
Edward McLaughlin Professor of Engineering

Department of Industrial & Manufacturing Systems Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

LTRC Project No. 98-20SS

CONDUCTED FOR

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

NOVEMBER 2002

ABSTRACT

This project developed a computer system to assist Louisiana Department of Transportation and Development (LA DOTD) maintenance managers in the preparation of zero-based, needs-driven annual budget plans for routine maintenance. This includes pavement, roadside, bridge maintenance, traffic operations & assistance to traffic, and ferry operations. The budget plan provides estimates for labor, overhead, equipment, and supply costs as well as contract maintenance.

The computer system provides management with ability to set planned service level targets for each maintenance function and to prioritize importance of both maintenance functions as well as use-based measures. It includes an optimization model that assists in allocating constrained financial resources among functions and districts based on these priorities and needs. It also includes a regression tool which can be used to automatically update the planning model based on recent historical data.

IMPLEMENTATION STATEMENT

The results of this work have been implemented in the form of a PC-based decision support system for assisting routine maintenance budget planning/allocation. This software can be directly installed and utilized by DOTD maintenance management.

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INTRODUCTION

Problem Statement

The LA DOTD currently lacks a functional computer model for allocating annual maintenance funds to the districts based on need rather than history. A model is required which will allocate limited maintenance funds as effectively as possible, as well as provide the LA DOTD with a rational decision process which can be used in justifying and defending allocation decisions to the state legislature and Louisiana's citizens.

Related Work

In December 1957, the Louisiana Department of Highways published a pamphlet entitled "Formula for Allocating Maintenance Funds" [*48*]. That work was the result of an investigation made by Mr. E.A. Landry of that department. He recognized that a relationship might exist and submitted the problem to the Division of Engineering Research at LSU. The investigation was completed in late 1962. The research did not yield a mathematical model to predict maintenance costs for concrete surfaces because of the limited scope of the project. The investigation, however, did show that five main effects appeared to account for much of the variability in maintenance costs: traffic volume, surface condition, subsoil condition, surface width, and right-of-way width.

In 1966, the report "Maintenance Formula for Asphalt Roads" was issued (State Project No. 736-00-64; FAP No. HPR-1(2)). It concludes with a model, although the fit is less satisfactory than the concrete model.

From 1965 to 1970, the consulting organization, Roy Jorgensen and Associates, conducted a study to design a maintenance management system for Louisiana (State Project No. 736-00-74). Budget cuts have since precluded the implementation of much of that study.

The Federal Highway Administration (FHWA) and the states, beginning in 1978, jointly developed and implemented a continuous data collection system called the Highway Performance Monitoring Systems (HPMS), but research on performance budgeting started well before that. Highway agencies at all levels of government have sponsored research involving one or more of the basic performance budgeting concepts. Analytical techniques have varied from those with a relatively simple cost accounting orientation to those dependent on quantitative analysis. Basically, two different approaches to performance budgeting were found in the literature survey. One is principal emphasis on work methods, production rates, and work scheduling and the other is the "total systems" approach. The following general characteristics were found in the literature survey:

a) Used work scheduling.

b) Recognized the importance of formalizing and integrating all performance budgeting elements.

c) Employed quantitative work measurement techniques.

The Transportation Research Board's (TRB) Pavement Management Handbook describes the application of different maintenance concepts in details. This also addresses the technology behind the pavement sealers, joint sealers, and processes in crack filling, patching, stripping, and so on.

TRB report 215 defines a pavement management system as a tool that provides decision makers at all levels of management with optimum maintenance strategies derived through clearly established rational procedures [*36*]. The report also laid out a framework for developing a pavement management system with a detailed description on characteristics for input models and output, provides alternative pavement management system viewpoints, and discusses specific existing technologies for PMS.

Maintenance levels of service influence the magnitude of the maintenance work (e.g., pavement patching, mowing, paint striping) and, therefore, the work scheduling requirements, work priorities, and resource allocations. However, selection of maintenance levels of service is influenced by a number of considerations that include safety, rideability, economics, environmental impact, protection of investment, and aesthetics. Thus to optimize the expenditure of maintenance resources, the TRB developed a systematic and objective method, based on decision analysis theory, to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structure, drainage ditches, etc.). These guidelines were published in the TRB Report No. 223 in 1980 [*25*].

Kulkarni et al. developed a systematic methodology for determining the maintenance levels of service that would maximize the user benefits subject to the constraints of available resources. [*22*]

As a continuation of the work done in 1980 on developing the guidelines for determining maintenance levels-of-service, the TRB developed a user's manual to instruct the maintenance personnel on the implementation of a simplified method to determine the optimal maintenance levels of service, given resource constraints of labor, material, and equipment. This manual was published in the TRB Report No. 273 in 1984 [*31*].

Since 1984, Highway Maintenance Management Systems have continually been developed and refined. However, because of inflation and limited funds, highway agencies have not been able to sufficiently fund maintenance to provide satisfactory levels of service. Realizing this, the Transportation Research Board conducted a study in 1986 to address the need of developing a method that could be used to evaluate agency and user costs resulting from decisions regarding maintenance service levels and rehabilitation timing. Life-cycle analysis (based on life-cycle costs) was identified as an effective method for such evaluations. This method is used to compute, for specified maintenance service levels, agency costs, vehicle-operating costs, traffic-interference costs, and other consequences such as accidents, lost time, pollution, and inconvenience. The results of this study were published in National Cooperative Highway Research Program Report No. 285 in 1986 [*10*].

Johnston (1988) presents executive summaries of two studies to develop components of a bridge management system [*19*]. In the first, a bridge management analysis method considering owner costs and user costs was developed to determine the optimum improvement action and time for each individual bridge in a system under various level of service goals. A computer program incorporating parameters and relationships of bridge ownership and user costs was created to analyze North Carolina bridges as an example. Based on the optimum improvement alternative selected for each individual bridge, the future funding needs, bridge conditions, load capacity, and bridge level of service deficiencies were predicted under different combinations of maintenance condition level of service goals and user level of service goals. The second study deals with the problem of identifying optimal maintenance levels of service for bridge maintenance activities. A systematic, objective methodology and a non-linear optimization program was utilized to structure and analyze a bridge maintenance model.

The Ohio Department of Transportation has a program of dedicated maintenance funding for various highway projects (1989) [*53*]. Monetary limits are established and enforced for projects ranging from roadside rest area maintenance contracts to two lane resurfacing. Allocation amounts and a brief description of the maintenance or repair requirements are given.

In the late eighties, the Pennsylvania Department of Transportation (PennDOT) piloted a matrix measurement concept developed in Oregon, the "Organizational Performance Index" (OPI) (1996) [*9*]. This tool provides the ability to track performance regularly and determines if improvement is being made based upon some predetermined indicators. Following successful implementation of OPI, PennDOT modified the concept in the early 1990s and applied it to measuring customer satisfaction. PennDOT now uses the Customer Service Index (CSI) throughout the Department to measure performance as determined by its customers.

Mann and Knapp et al. (1997) evaluated Louisiana's current computerized maintenance management systems and recommended improvements [*29*]. They developed a long-term capital outlays budget planning structure for achieving a fully funded maintenance program. Mann and Knapp et al.'s research also revealed that the current CMMS has significant deficiencies in terms of supporting critical maintenance management processes, data quality and integration. They described the present system as an extended version of an accounting support system. Their analysis of current maintenance funding indicated that maintenance in Louisiana was seriously under funded.

Many Texas Department of Transportation (TxDOT) District Engineers had expressed a concern to the Senior Management team about not having enough maintenance funds. In March 1996, the Executive Director developed a "Continuous Improvement" team and charged them with extensively evaluating the Routine Maintenance Budget issue and developing a formula driven process, by category of work, to equitably distribute the routine maintenance budget. The team was to develop "needs-based" formulas for most individual maintenance activities. The budget allocation was made by using fiscal year 1995 data in the formulas. The data needed for the formula is to be updated annually. The budget formulas developed are based upon road inventory and condition, making the process dynamic. As inventories increase or pavement condition scores change, the funding levels change. The districts with the problems get more money. The budget formulas were developed at a "Tolerable" level of funding. The system can be utilized to develop a "Tolerable" estimate of needs. Slight modifications can produce an "Acceptable" or "Desirable" needs estimate. The quantities of work identified in the budget process compare favorably with the existing quantities of work by district. This process results in an equitable level of funding for all districts.

Al-Monsoor et al (1994) studied the effect of various maintenance treatments of flexible pavement condition [*1*]. Pavement roughness was used as direct quantitative measures of pavement condition. A database from the Indiana Department of Transportation (INDOT) was used in this research. Possible factors, which can affect pavement condition, were investigated in this analysis. Maintenance-effect models had been introduced to examine the effect of various maintenance treatments on pavement roughness. A maintenance effectiveness measure was also developed to compare various treatments.

Kardian and Woodward (1990) discuss the maintenance quality evaluation program formally implemented by the Virginia Department of Transportation (1989) to increase the productivity and effectiveness in highway maintenance operations [*21*]. This research qualitatively assessed the level of maintenance for flexible and rigid pavements, stabilized roadways, roadway shoulders, drainage, traffic control and safety, roadside, and structures.

Miquel and Condron (1991) report the results of a joint research study by the United States Federal Highway Administration and the World Bank to assess contract road maintenance practices in selected countries with the objective of providing operational guidance on planning, budgeting, tendering, and administering such works [*32*]. The report describes the reasons for using contract maintenance, the classification of maintenance operations, the selection of work items to be contracted, and the types of contracts used for maintenance works. The procedures for tendering contracts and supervision of works are reviewed. The report further compares contract maintenance with force account work and discusses the transition from force account (direct labor) operation to contract maintenance.

The PAVER system developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) in 1982 provides the ideal environment for creating standardized work plans. The system includes a mainframe version (PAVER) and a microcomputer version (Micro PAVER) to provide the Army installation Directorate of Engineering and Housing (DEH) with an easy-to-use decision making tool for pavement maintenance management. System capabilities include data storage and retrieval, pavement condition prediction, budget planning, determination of Maintenance and Repair (M&R) needs, and economic analysis. The PAVER system can help DEH personnel prioritize the pavement sections requiring maintenance and/or repair. It also helps the engineer to choose the best maintenance and rehabilitation alternative. The goal of this technology is to maximize the pavement condition with the available funds. The pavement condition rating used in PAVER is the Pavement Condition Index (PCI), which is based on the type, quantity, and severity of distresses present. As a part of the implementation of PAVER system, a priority scheme for the selection of pavement sections needing major repair was created. The scheme developed was a "worst-first" priority strategy based on pavement condition and rank. A shortcoming to this scheme is that cost and benefit of repair are not considered as criteria. Although the priority scheme is a vast improvement over past methods, it is simply a "worst-first" method.

If cost were also considered in the selection process, an improvement would result by taking advantage of the fact that as PCI drops, cost for repair increases.

Uzarski and Darter (1986) addressed this issue in their research. They incorporated cost and benefit criteria as additional parameters in the selection of pavement sections for major repair [*51*]. Six strategies were considered: 1) do nothing, 2) use the existing priority scheme, 3) use a revised priority scheme that takes cost into account, 4) repair when needed, 5) use section benefit-cost optimization with variable utility, and 6) use section benefit-cost optimization with constant utility. The research also revealed that by revising the priority strategy or by using benefit-cost optimization techniques, an improved network condition could result at a lower overall cost.

A project of the National Cooperative Highway Research Program (NCHRP) (Project 3-56) titled "System-wide Impact of Safety and Traffic Operations Design Decisions for Resurfacing, Restoration, or Rehabilitation (RRR)" is researching to develop a process for allocating resources to maximize the effectiveness of RRR projects in improving safety and traffic operations on the non-freeway highway network. This project is envisioned to undertake the following: a) critically review the literature to identify the safety and traffic operations impact associated with RRR projects; b) contact federal and state agencies to identify their policies, standards and programs associated with RRR projects; c) conceptualize a process to maximize the cost-effectiveness of RRR projects under the constraints of limited resources; d) compare the data requirements defined for the process with the types of data currently available; e) gather the data needed in accordance with the plan approved by the panel; f) develop the process for evaluating the cost-effectiveness of safety and traffic operations improvements associated with RRR projects; g) demonstrate the process by applying it to a representative set of projects in cooperation with three or more agencies. This information was made available through a posting of the status report and objective on the Internet.

The "Trunk Road and Maintenance Manual" (1992), a publication of the United Kingdom's Department of Transport, deals with several aspects of routine highway maintenance [*50*]. Volume 1 provides sections on routine maintenance management, minor carriageway repairs, footways and cycle tracks, curbs, edgings, pre-formed channels, drainage, motorway communications installations, as well as other topics. Volume 2 covers maintenance of highway structures such as bridges, subways and underpasses, retaining walls, sign signal gantries, and high masts and catenary lighting.

Sinha and Fwa (1993) present the results of a research study, the objective of which was to develop a systematic decision-making framework to enhance the efficiency and effectiveness of the existing highway maintenance management practices in Indiana [*45*]. The required forms of data and the recommended basis and procedures of decision making are discussed for the following: assessment of maintenance needs; establishment of performance standards; determination of costs of maintenance treatments; setting up an integrated database; priority rating maintenance activities; and optimally programming and scheduling maintenance activities. The proposed framework intends to help management plan and monitor highway maintenance programs to achieve better results.

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Sutarwala and Mann (1963) were the first to develop a conceptual mathematical model in the form of an equation that could predict the yearly maintenance cost of a given mile of roadway section [*48*]. Mann (1963) continues the work in this area and develops a mathematical model to predict highway maintenance costs by modifying the initial model to ensure the adequacy of maintenance [*27*]. He suggests that the mathematical model could be used to compute future maintenance requirements and to calculate the costs within various activity classifications (patching, grass cutting, etc.).

The Highway Research Board Report No. 42, published in 1967, presents the development of a unit maintenance expenditure index, expected to be useful to a highway administrator or engineer in evaluating past and predicting future highway maintenance costs trends [*18*]. It further recommends that a new Unit Labor Cost Index, Unit Equipment Cost Index, and a Unit Material Cost Index be established and computed annually.

In the seventies, with numerous highway agencies undertaking the development of systems for improving maintenance management systems, the Highway Research Board realized the need and hence developed a model for maintenance performance budgeting to make budgets effective management tools. The model was developed in accordance with the establishment of maintenance levels; definition of workload; determination of resource requirements; procedures for management planning, evaluation, and control; records and reports to serve the budget system; and simplicity and economy of installation and operation as the basic criteria. This model was published in Highway Research Board Report No. 131 in 1972 [*38*].

To help highway maintenance management plan maintenance activities, Mann et al. (1976) developed a series of models to estimate maintenance costs requirements by applying the least squares technique to a database derived from the historical records maintained by the Louisiana Department of Highways [*30*]. The models could be used to compute the costs of surface maintenance, shoulder and approach maintenance, roadside and drainage maintenance, structure maintenance, traffic surface maintenance, river-crossing operations maintenance, and maintenance overhead and administration costs.

In an attempt to identify and implement efficient highway maintenance operations, the TRB conducted a study of the recording and reporting methods for highway maintenance expenditures used by eleven states. The study shows that numerous types of reports were generated but suggests that reports be categorized as audit, inventory, planning, equipment use, performance, budget control, special analytical, and exception reports. The study recommends that an ideal recording and reporting system should be capable of furnishing maintenance activity and cost information to the highway designer who is concerned with alternative life-cycle analyses. The findings of this study were published in the TRB Report No. 46 in 1977 [*41*].

Niessner (1978) reports a series of value engineering studies performed by the FHWA and the TRB with an aim to optimize the expenditure of maintenance resources [*33*]. The studies include the following maintenance activities: snow and ice control (operations and materials), shoulder maintenance, bituminous patching, repair of continuously reinforced concrete pavement, sign maintenance, bridge painting, pavement markings, repair of pavement joints, and maintenance of rest areas. The studies prove that the value engineering process can be successfully used to perform an in-depth analysis of maintenance activities.

In 1981, the TRB published Report No. 80, which reviews the development of highway maintenance budgets and the steps involved in the approval process of different highway agencies [*12*]. The report also includes a compilation of research needs related to formulating and justifying highway maintenance budgets. These needs include the development of budget tools to relate maintenance expenditures to long-term benefits, cost-effective maintenance strategies, and objective procedures to establish priorities among maintenance deficiencies.

Sharaf and Sinha (1978) develop a methodology for using available state data on traffic, highway system characteristics, and routine pavement maintenance records to develop models relating the cost of routine maintenance to pavement system characteristics [*44*]. The model can therefore assist in preparing a pavement maintenance program and in making decisions regarding the trade-offs between rehabilitation and routine pavement maintenance.

Kampe et al. (1978) develop a new approach to estimate labor resource needs for a highway maintenance program to be used in budgeting [*20*]. Seven calculation methods, including historic projection, frequency calculation, condition evaluation, organization plan, proration, and capital project scheduling plan, are employed to correlate workload and labor resources. The authors suggest that this model be used to make budget recommendations to top management.

Responding to concerns over the inability of capital budgeting models for planning long-term highway maintenance, Cook (1984) develops a financial planning model to determine minimum annual expenditure requirements to meet service level objectives by road category, based on traffic density [*7*]. He also uses goal programming to determine maintenance strategies and allocate funds to achieve target service levels for each road category.

Golabi, et al. (1982) describe a pavement management system which produced both short-term and long-term optimal maintenance policies for the Arizona highway network. [*14*]. The foundation of this pavement management system is a Markov decision model which determines cost-minimizing maintenance schedules for each mile of the system, taking into account management decisions, budget allocations, engineering procedures, and environmental factors such as altitude, temperature, moisture conditions, and traffic density. The authors show that the use of this pavement management system led to the development of reliable predictive performance models that have enhanced understanding of pavement deterioration and effectiveness of various maintenance procedures.

Chong and Phang (1985) discuss the steps taken by the Ontario Highway System to prolong the life of highway pavements [*5*]. Perhaps the most significant contribution of this research is the detailed guidelines for situations in pavement maintenance where preventive maintenance affects the life of pavements. The guidelines consist of the identification process, treatment selection, and performance standards to be used. The research describes the practices of identifying and classifying a typical deficiency, selection of the most cost-effective treatment, specifications for equipment and materials needed to carry out the treatment, and proper work methods.

Theberge (1987) undertook a study to examine the mathematical relationship between a variety of pavement attributes and other quantifiable variables on one hand, and maintenance needs and priority evaluations made by district area supervisors on the other [*49*]. With some assistance from the Maine Department of Transportation and by using the Delphi technique, threshold levels for preventive maintenance, capital maintenance and rehabilitation are established. A model to predict repair categories is also developed.

Poister (1983) discusses the productivity-monitoring program for highway maintenance implemented by the Pennsylvania Department of Transportation, which links productivity to a variety of performance indicators, including output, costs, and highway conditions [*39*]. Decreased labor costs, increased maintenance output, and improved highway conditions were the major benefits gained by implementation of this program.

Cochran et al. (1991) describes a research project funded by the Arizona Department of Transportation that resulted in a decision support system for transportation planners of goods movement on highways [*6*]. They point out that this is the first DSS to include simultaneous embedded computer simulation and database tools to generate summaries of pavement maintenance activities.

Evans et al. (1992) conducted a study aimed at improving the effectiveness and efficiency of routine road maintenance activities by emphasizing a needs-driven approach to determining an optimal arrangement for road maintenance patrol resources [*11*].

Smith et. al. (1996) describes a methodology to develop possible global maintenance strategies for a highway network using the Financial Network Optimization System module from the RTA NSW pavement management system [*46*]. The authors describe their methodology including a discussion of the appropriate condition data to use. They proposed the use of the Maintenance Level of Service (MLOS) developed by the Texas Department of Transportation to assist in the interpretation of the condition data and determine which condition parameter (cracking, rutting, or roughness) is driving the maintenance effort.

OBJECTIVE

The objective of this research is to develop a zero-based budgeting system for routine maintenance expenditures, in which allocations are justified on quantifiable need and management service objectives to equitably and effectively distribute routine maintenance funds to the districts.

SCOPE

The focus of this work will be on the development of a computer model for allocating funds to routine maintenance activities. These activities will include all routine maintenance functions performed in the areas of pavement, roadside, bridges, traffic operations and traffic assistance, and ferries, but specifically exclude consideration of funding for larger reconstruction and major overhaul work on these structures. Supplies and contract maintenance costs relating to routine maintenance will be included in the model.

METHODOLOGY

Following is an overview of the methodology taken in this study:

1. **Data Collection.** Existing data sources were researched and data was collected relevant to the project. This section details what data was collected and what data is required by the planning system.

2. **Base Function Calculations.** Consists of two components:

   - **Maintained Units**. Calculation of the total units under maintenance in each district, system, and maintenance function combination.

   - **Average Unit Accomplishment Cost.** Calculation of the average unit cost of accomplishment for each district, system, and maintenance function for personnel, equipment, and material costs.

3. **Accomplishment Units Prediction Calculations**. Regression and analysis of variance (ANOVA) was applied to develop a regression model for predicting how many units of accomplishment are required for each function at a baseline service level.

4. **Base Function Cost Calculations**. Calculation of total cost model (excluding overheads and fringe) for each maintenance function.

5. **Service Level Calculations**. Identification of service level measurement factors, and development of a predictive relationship between amount of maintenance dollars allocated and service level performance.

6. **Fringe & Overhead Calculations.** Addition of fringe and overhead rates to determine the total maintenance costs by function, district, and quarter.

7. **Function Prioritization Model**. Development of a model for representing effectiveness priorities between functions.

8. **Allocation model.** Development of a budget allocation model for optimizing service levels and/or budget levels.

The following sections detail each of these steps.

Data Collection

Databases

Historical data was collected from the following LA DOTD databases:

- MAINTENANCE OPERATIONS SYSTEM (MOPS) INVENTORY

  The inventory database contains road inventory data by control section/subsection. This data is critical to the accuracy of the maintenance planning model; however, it is not updated frequently and its accuracy is questionable. It also only indicates the inventory at the time of the last update – no inventory history is maintained that can be related back to maintenance requirements and cost for a particular time.

The following data is utilized from this database:

- Length
- Miles Concrete
- Miles Concrete Equiv. 2 Ln
- Miles Asphaltic (bit) Concrete
- Miles Asphaltic (bit) Concrete Equiv. 2 Ln. – P1200 ADT
- Miles Asphaltic (bit) Concrete Equiv. 2 Ln. – M1200 ADT
- Miles Composite
- Miles Composite Equiv. 2 Ln. – P1200 ADT
- Miles Composite Equiv. 2 Ln. – M1200 ADT
- Miles BST (asphalt)
- Miles Gravel
- Miles Shoulder Non-paved Turf
- Miles Shoulder Non-paved Aggregate
- Miles Shoulder Paved
- Miles Mowing Rural
- Miles Mowing Urban
- Miles Sweeper Curb
- Physical Acres
- Vehicle Miles Travel
- Number of Litter Barrels
- Number of Rest Areas
- Number of Crash Devices

During the import process, a sum of each data field except vehicle miles traveled is also created across each unique district/system code combination. A weighted summarization of Vehicle miles is calculated as =Sum(Vehicle Miles*Length)/Sum(Length).

- MOPS WORK ORDER (WO) HISTORY

MOPS WO history data is the basic work order expense and accomplishments data. The import table from the MOPS WO mainframe file includes the following for each unique combination of <u>system, district, parish, gang, function, fiscal year, and control section</u>:

- Fiscal Year
- System
- District
- Parish

- Gang
- Control Section
- Total manhours – regular time (does not include fringe)
- Total manhours – overtime (overtime pay=1.5x regular pay)
- Total personnel costs
- Total equipment costs
- Total material costs
- Total accomplishment quantity

- NEEDS SURVEY

The NEEDS survey database contains data on road condition, deficiency analysis, and improvement planning. It overlaps the MOPS inventory database to some extent, particularly on mileage figures and average daily traffic (ADT), and appears to be more up to date in these aspects, although it still is not updated annually for each control section.

The NEEDS data is primarily used as covariates in the unit accomplishments prediction model.

The NEEDS database gives details down to parts of control section, and the following data is collected.

- Control Section
- Logmile
- Length (miles)
- District
- Parish
- System (Functional Class)
- Lanes
- ADT
- Terrain (0=flat, 1=rolling)
- Condition Rating
- Safety Rating
- Total Rating
- Surface Type
- Pave Type
- Base Type
- Last Year Improved
- Years Since Last Improved (calculated from above as Year(Now)-Last Year Improved)

This data is aggregated on import to the control section level:

- Control Section
- Total section length (miles)

- District
- Parish
- System (Functional Class)
- Avg Lanes = Sum(Lanes*Length*ADT) / Sum(Length*ADT) over all subsections of the control section.
- Avg ADT = Sum(ADT*Length/Lanes) / Sum(Length/Lanes) over all subsections of the control section.
- Avg Terrain = Sum(Terrain*Length) / Sum(Length)
- Avg Condition Rating
- Avg Safety Rating
- Avg Total Rating
- Total Eq Lane Miles (miles) for each surface type = Sum(length*Lanes) by surface type
- Total Eq Lane Miles (miles) for each pavement type = Sum(length*Lanes) by pavement type
- Total Eq Lane Miles (miles) for each base type = Sum(length*Lanes) by base type
- Avg Last Year Improved = Sum(Last Year Improved * Length*Lanes) / Sum(Length*Lanes)
- Avg Years Since Last Improved = Year(Now)-Avg Last Year Improved

- STRUCTURES

The Structures database contains the inventory of bridges and overpasses. For each unique combination of district and summary, the following is required.

- District
- System
- Total Number of bridges
- Total Number of non-timber bridges
- Total Number of timber pile bridges
- Total Number of movable bridges
- Total Bridge length (in miles)
- Total square feet of bridge concrete deck
- ADT & Length Weighted Bridge Condition Rating, all bridges
- ADT & Length Weighted Bridge Condition Rating, Non-Timber
- ADT & Length Weighted Bridge Condition Rating, Timber
- ADT & Length Weighted Bridge Condition Rating, Movable Bridges
- Total Number of Railroad Crossings

- TRAFFIC

  The Traffic signal inventory provides inventory data on traffic signal devices. For each district / system combination, the following is collected:

  - Number of signal devices

- FERRY CROSSINGS

  A list was obtained of ferry crossing locations. The following information is required for each location:

  - District
  - Description

  In addition, a total count of ferry crossings would be calculated for each district.

- TOLLS

  A list was obtained of toll locations. The following information is required for each location:

  - District
  - Description

  In addition, a total count of tolls would be calculated for each district.

All records from each database for 1992-2001 were dumped to text files from the mainframe data stores, and subsequently ported to LSU via FTP. The data was subsequently imported and summarized as needed into Access.

Base Function Calculations

In this section, the procedure for calculating the base number of units under maintenance and the average unit accomplishment cost are detailed. Appendix A provides a brief description of all the maintenance functions and their accomplishment units.

Maintained Units

Following are the calculations used for determining the base number of inventory units maintained by each function. The calculations are performed for each district / system combination by function.

Bituminous Surface Maintenance Functions (411-419)

=Total Miles Asphaltic Concrete Equivalent 2 Lane +
Total Miles Asphaltic Concrete Equivalent 2 Lane P1200 +

Total Miles Asphaltic Concrete Equivalent 2 Lane M1200 +
Total Miles BST

Except for function 418 (cutting/burning bumps):

=Total Miles Asphaltic Concrete Equivalent 2 Lane +
Total Miles Asphaltic Concrete Equivalent 2 Lane P1200 +
Total Miles Asphaltic Concrete Equivalent 2 Lane M1200

Concrete Surface Maintenance (421-429)

=Total Miles PC Concrete Equivalent 2 Lane

Gravel or Shell Surface Maintenance (439)

=Total Miles Gravel

Shoulder Maintenance (441-459)

For functions 441-445 (non-paved shoulder):

=Total Miles Shoulder Non-Paved Turf +
Total Miles Shoulder Non-Paved Aggregate

For functions 452-455 (paved shoulders):

= Total Miles Shoulder Paved

For function 459 (other shoulder maintenance):

=Total Miles Shoulder Paved +
Total Miles Shoulder Non-Paved Turf +
Total Miles Shoulder Non-Paved Aggregate

Roadside and Drainage Maintenance (461-479)

For functions 461-468,471-473,475, 477,479 (general ditch and drainage servicing):

=Total Length

For functions 470,478 (mowing):

=Total Miles Mowing Rural +
Total Miles Mowing Urban

For function 474 (litter barrels):

=Total number of litter barrels

For function 476 (herbicide):

=Total Miles Mowing Rural + Total Miles Mowing Urban

Bridge and Structure Maintenance

For functions 481,486,490-494:

=Total Bridge Length

For functions 483,499:

=Total Number of Bridges

For functions 495-496:

=Total Number of Movable Bridges

For function 487(non-timber foundation service):

=Total Number of Non-timber bridges

For function 485 (concrete deck maintenance):

=Total square feet concrete deck

For function 497 (maintenance of ferry approaches, bridges, and rail crossings by others):

=Total Number of Bridges +
Total Number of Ferries +
Total Number of Rail Crossings

Traffic Services (511-559)

For functions 511,533,534,538,542,559 (snow & ice control, traffic signs, guardrails, etc):

=Total Miles

For functions 528, 531, 539, 540 (pavement striping & reflective tape):

=Total Miles – Total Miles Gravel

For functions 532, 535, 536 (signal devices):

=Number of Signal Devices

For function 556 (sweeping):

=Miles of sweeper curb

Maintenance of Ferry Approaches (434)

=Total Number of Ferry Crossings

These calculations are performed for each function / system / district combination, and the results are stored into an Access table.

Average Unit Accomplishment Costs

Average unit accomplishment costs are calculated for each function, district, and system combination for the latest fiscal year available. The costs are calculated separately for regular time personnel, overtime personnel, equipment, and materials.

The unit cost is calculated by dividing the total cost in each cost category by the total units accomplished. It should be noted that, while excellent records are maintained on costs, the quality of the accomplishment data is suspect. Many WO's had costs with 0 accomplishment units noted. Thus, the accuracy of the unit costs will be affected. To avoid biasing the unit cost upward as a result, only WO's having non-zero accomplishment units are considered in the calculation. The calculated unit cost values can be overwritten by the planner.

Fringe benefit and overhead cost rates are calculated as well but can be overwritten by the planner by specifying a fringe benefit and overhead rate (%).

Predicted Unit Accomplishments Required

In this step, a prediction of the number of accomplishment units required in the next year is calculated. This prediction is based on continuation of the same service level as the previous year (changes in service level are handled in a later step).

Unit Accomplishment Rate (UAR) Model

The UAR model is used to predict the average annual and quarterly number of accomplishment units for each function per maintained unit for that function –i.e., the unit accomplishments rate per maintained unit.

This model is based on a linear regression model of the following form:

$$UAR_{i,q,s} = C_{0,i,q,s} + C_{1,i,q,s}F_1 + C_{2,i,q}F_2 + ... + C_{N,i,q,s}F_N \quad (1)$$

where:

$UAR_{i,q,s}$ = UAR for function i in quarter q

$C_{j,i,q,s}$ = Fit Coefficient j for function i, quarter q. C_o is a baseline coefficient.

F_j = Covariate factor j

The covariate factors are condition-related values and roadway characteristics that might affect the accomplishments rates. The following factors were considered:

- Weighted ADT
- Weighted Total Condition Rating
- Weighted Total Safety Rating
- Weighted Total Rating
- Lane Miles of Each Surface Type
- Lane Miles of Each Pavement Type
- Lane Miles of Each Base Type
- Weighted Lanes
- Weighted Years Since Improved
- Lane Miles Concrete
- Lane Miles Concrete Equivalent 2 Lane
- Lane Miles Asphaltic Concrete Equivalent 2 Lane
- Lane Miles Asphaltic Concrete Equivalent 2 Lane P1200ADT
- Lane Miles Asphaltic Concrete Equivalent 2 Lane M1200ADT
- Lane Miles Composite
- Lane Miles Composite Equivalent 2Lane P1200ADT
- Lane Miles Composite Equivalent 2 Lane M1200ADT
- Lane Miles Asphalt
- Lane Miles Gravel
- Miles Shoulder Nonpaved

- Miles Shoulder Nonpaved Turf
- Miles Shoulder Nonpaved Aggregate
- Miles Shoulder Paved
- Miles Mowing Urban
- Miles Mowing Rural
- Miles Sweeper Curb
- Physical Acres
- Vehicle Miles
- Number Litter Barrels
- Number Rest Areas
- Number Crash Devices

Models were fit and tested for explanatory power using SAS's (a well-known statistical package) stepwise multiple variable regression analysis procedure, with a 95% confidence level. SAS's stepwise regression procedure was used, which not only fits coefficients but also selects which variables to include in the model as most significant.

To make it easier to refit the model, a procedure was developed for automatically producing the necessary SAS data sets and programs, calling SAS to execute the programs, and importing back the model fit results. This procedure assumes that SAS is installed on the same computer. It is also possible to export the data and then separately import the result files if SAS is not available locally.

The DSS program developed (described later in this section) also has a built-in regression procedure to allow the model coefficients to be regularly updated. This procedure is not stepwise, and assumes that all the significant variables identified in the above procedure are included in the predictive model for each block. The procedure then recalculates the coefficients based on a specified year range of data.

Base Function Costs Calculations

In this step, the predicted cost by function in each cost category (regular time, overtime, materials, and equipment), and by quarter, district, and system is calculated. This is simply the multiplication of Units Required * Average Unit Cost, as follows:

$$C_{c,f,q,d,s} = N_{f,d,s} * P_{f,q,d,s} * U_{c,f,d,s} \qquad (2)$$

where:

c = Cost Category (regular time labor, overtime labor, materials, equipment)

f = Function index

q = Fiscal quarter (1 through 4)

d = District

s = System type

$C_{c,f,q,d,s}$ = Base cost c for function f in (q,d,s)

$N_{f,d,s}$ = Maintained units for function f in (d,s)

$P_{f,q,d,s}$ = Predicted Accomplishment Unit Rate for function f in (q,d,s)

$U_{c,f,d,s}$ = Unit cost c for function f in (d,s)

In addition, fringe costs are calculated and stored as well as added to the regular and overtime costs:

$$F_{c,f,q,d,s} = FR * C_{c,f,q,d,s}$$
$$C_{c,f,q,d,s} = F_{c,f,q,d,s} + C_{c,f,q,d,s} \quad (3)$$

where:

FR = State fringe benefit rate

$F_{c,f,q,d,s}$ = Fringe benefits for function f in (q,d,s)

Service Level Model & Calculations

In defining the cost equations in the prior subsections, it is implicitly assumed that historical maintenance service levels are continued into the future. This may not be adequate. Ideally, budget funding should also be a function not only of the predictive factors listed in the prior section, but also of the desired level of service. There are two possible approaches to this problem:

- **Empirical Estimation.** Equations are fit to model the predicted effects on each service objective (or combined measure) at different levels of maintenance effort (cost). This is the approach that the LA DOTD PAVE system ultimately hopes to achieve. Generally, accurate data collected in abundance under controlled testing conditions is needed to develop acceptable models. Specific objective measures must be defined and regularly assessed.

- **Subjective Estimation.** In the absence of sufficient quality data, subjective methods can be used to characterize the relationship between maintenance effort and service level provided.

Because of the absence of controlled historical data, the latter approach is utilized in this methodology:

- Condition data in NEEDS is not updated on an annual basis, and may be at least somewhat dated for many road sections.

- The impact of dollars spent on routine maintenance functions on pavement life, safety, and user satisfaction is not characterized. Even the impact on expenditures indirect measures (such as safety rating) is not available.

- Unlike a controlled experiment, past effort levels in the districts were not "scientifically" controlled. As a result, differences in objective measures may be due to differences in maintenance effectiveness among districts/systems rather than maintenance dollar support level.

- Maintenance effort levels are fairly standardized between and within locations. As a result, there is not a great range of maintenance effort levels on which to fit an equation.

An attempt was made earlier in this study to isolate service level effects. A sophisticated model was fit using regression analysis that attempted to isolate the effect of differences in maintenance expenditures between control sections with similar characteristics (system, ADT, surface/pavement/base type, and safety/condition ratings) on subsequent condition and safety rating. However, as a result of the issues discussed above, the resulting model was statistically weak and did not provide any significant value in predicting the relationship between expenditures and service levels achieved.

In the absence of suitable historical data for developing a model, a subjective model has been developed. Actual data was not collected from LA DOTD personnel for fitting the model; however, the mechanism for collecting, fitting, and utilizing the data has been built into the budget planning DSS. This is described in the following paragraphs.

To collect the service level data, district and area supervisors would be asked to indicate how much effort (as a % of the previous year's effort) would be required to provide 1) a "good" level of service, and 2) a "minimum" adequate level of service for each function / system combination. These would then be multiplied by the previous year's unit accomplishment rates. The results would then be averaged within each district to get a 90th ("good") and 10th ("minimum adequate") percentile unit accomplishment rate estimate respectively for each district / function / system combination. A linear function is assumed for the relation between service level and unit accomplishment rate. Based on this, the service rate for the previous year for each district / function / system combination is calculated and stored as well.

Service level input data may be entered directly into the DSS by form, or imported from a text file, Excel spreadsheet, or Access database table.

In specifying future desired service levels, the following linguistic terms, their basic intention, and associated service level (on a scale from 0 to 1) is used:

Table 1: Service level terms

Linguistic Term	Meaning	Service Level
Inadequate	Not being serviced at the minimum level required to keep roadways in service, provide basic services, or avoid liability due to negligence	0.0
Minimum	Minimum service levels required to keep roadways in service; provide basic service for ferries, tolls, or rest areas; and avoid liability due to negligence.	0.25
Satisfactory	Sufficient to keep roadway in good condition and general user satisfaction.	0.5
Good	Sufficient to maintain or extend roadway life and/or maintain high user satisfaction levels.	0.75
Excellent	Highest reasonable level of effective service.	1.0

Fringe, Overhead, & Total Cost Calculations

After application of the service level adjustment, fringe and overhead costs are calculated (and stored) and applied to the adjusted base costs to arrive at total costs by function, district, system, and quarter:

$$\begin{aligned} O_{f,q,d,s} &= OR * \sum_{\forall c} C_{c,f,q,d,s} \\ TC_{f,q,d,s} &= O_{f,q,d,s} + \sum_{\forall c} C_{c,f,q,d,s} \end{aligned} \qquad (4)$$

where:

c = Cost Category (regular time labor, overtime labor, materials, equipment)

f = Function index

q = Fiscal quarter (1..4)

d = District

s = System type

$C_{c,f,q,d,s}$ = Base cost c for function f in (q,d,s)

OR= State overhead rate (as a %)

$O_{f,q,d,s}$ = Overhead cost for function f in (q,d,s)

$TC_{f,q,d,s}$ = Total cost (including overhead) of function f in (q,d,s)

In addition, the following aggregations are also calculated and stored for planning purposes:

- Sum of total costs by function, quarter, and district
- Sum of total costs by quarter and district
- Sum of total costs by function and district
- Sum of total costs by function
- Sum of total costs by district (the total district routine maintenance budget)
- Sum of total costs (the total state routine maintenance budget)

Function Prioritization Model

To make effective decisions on allocation of limited maintenance funds to maintenance functions, it is necessary to have some form of prioritization scheme in place.

The primary objectives of any maintenance organization include:

- **Safety.** Maintenance should be performed to keep roads clear of large faults, bumps, ruts, debris, and so forth, that might cause safety hazards during normal operation and during accidents
- **Preservation of Assets.** Application of preventive maintenance can slow / prevent deterioration of function of pavement, structures, drain systems, etc.
- **User Satisfaction.** For pavement, right-of-way, and structure maintenance this can be divided into:
  - *Ride Quality Perception.* Perceived ride comfort, for all user classes.
  - *Aesthetics.* Visual perception of pavement, structures, right of way.

  For toll services, satisfaction is primarily measured on *service time*. For ferry crossings, satisfaction is primarily based on the *number of crossing* made daily.

Different priorities (weightings) may be assigned to these objectives. Furthermore, these priorities may differ across function classes (systems) and districts.

This work did not include a study to determine LA DOTD's actual function priorities. However, it did build in the mechanism for collecting this data and incorporating it into the budget-planning model.

It is assumed that a survey is conducted of district and area supervisors, and transportation engineers to determine the function priorities. Each participant would first be asked to perform a forced ranking (1-5) of the importance of each objective for each system within his or her district:

- Safety
- Preservation of Assets
- Ride Quality
- Aesthetics
- Service (tolls, ferries, rest areas)

This information would be tabulated into a file or table format similar to the following

Table 2: Objective rankings format

District	ParticipantID	System	Objective	Rank
1	1	1	1	1
1	1	1	2	3
1	1	1	3	2
1	1	1	4	4
1	1	1	5	5
1	2	1	1	2
etc...				

The participants would then be asked to provide a ranking on a scale of "Very Effective" (3), "Moderately Effective" (2), or "Little or No Impact" (1) for each function towards meeting each objective. The participant need only identify those functions with particularly high (or low) effectiveness relative to other functions – a blanket rank can be assigned to all other functions using the function number "0." This information would then be tabulated into a file or table format similar to the following:

Table 3: Function effectiveness rankings format

District	ParticipantID	Objective	System	Function	Rating
1	1	1	1	411	3
1	1	1	1	412	1
1	1	1	1	0	2
1	1	2	1	528	3
1	1	2	1	534	3
1	1	2	1	0	1
etc...					

This data may be entered directly into the DSS in the formats indicated above, or imported from a text file, spreadsheet, or Access database table. The following process is used to summarize the ranking into priority weightings for each function / district / system combination.

1. The data file is read in. For each participant, any objective/function/district/system combination not specifically ranked is assigned either the blanket ranking, or if no blanket rating is defined, a rating of 1 is assigned.

2. The average objective ranking, $O_{o,d,s}$, is calculated for each objective / district / system combination. The average function effectiveness ranking, $R_{o,f,d,s}$, is calculated for each objective / function / district / system combination.

3. A priority weight for each function / district / system combination is calculated as follows:

$$W_{f,d,s} = \sum_{o} O_{o,d,s} * R_{o,f,d,s} \qquad (5)$$

where:

o = objective o (safety, preservation, ride, aesthetics, service)

$W_{f,d,s}$ = priority weighting for function f, system s, in district s

$O_{o,d,s}$ = ranking of objective o overall for system s in district d

$R_{o,f,d,s}$ = ranking of effectiveness towards objective o for system s in district d

4. Priority weights are then normalized on districts to ensure that districts don't give high priorities to all functions to insure a higher budget allocation:

$$W_{f,d,s} = \frac{W_{f,d,s}}{\sum_{f,s} W_{f,d,s}} \qquad (6)$$

5. Finally, all priority weights are normalized to a total range of 1 to 10 in order to ensure against scaling problems in the allocation optimization model:

$$W_{f,d,s} = 1 + 9 * \frac{W_{f,d,s}}{\sum_{f,d,s} W_{f,d,s}} \qquad (7)$$

Allocation Model

The basic cost model developed previously will give us an accurate projection of maintenance costs given that maintenance effort levels remain consistent and budget limitations are not present. However, the planning process usually demands some level of "what-if" analysis. To this end, an optimization model was developed and integrated into the DSS to assist planners in this analysis. The model can be used in three ways:

- *Constrained Budget, Unconstrained Service Levels.* In this case, a fixed total maximum annual maintenance budget is specified as a constraint, and the model seeks to allocate funds so as to maximize the prioritized aggregate service levels.

- *Constrained Budget & Service Levels.* In this case, the minimum required service level is specified for some or all functions, in addition to the budget constraint. The model seeks to allocate funds so as to maximize the prioritized aggregate service levels while meeting the minimum service level requirements specified.

- *Constrained Service Levels, Unconstrained Budget.* In this case, required service levels are specified for all functions. The model calculates the total cost to meet the service level requirements.

The basic optimization model is as follows. The objective is to maximize the priority weighted (function/district/system priorities $W_{f,d,s}$) aggregate service level WSL:

$$\text{Max} \quad WSL = \sum_{f,d,s} W_{f,d,s} * SL_{f,d,s} \qquad (8)$$

Subject to the following constraints:

1) Constraint on Budget (B)

$$\sum_{f,q,d,s} TC_{f,q,d,s}(SL_{f,d,s}) \leq B \qquad (9)$$

2) Service Level limits

$$0 \leq SL_{f,d,s} \leq 1 \quad \forall \ f,d,s \qquad (10)$$

The above model is guaranteed to have a solution for non-negative budget B.

Minimum required service level constraints may be added for one or more functions to the previous model. These constraints take the form of:

$$SL_{f,d,s} \geq MinSL_{f,d,s} \tag{11}$$

for each (f,d,s) combination for which a minimum requirements is specified. Note that it is possible in this case that the model may not have a feasible solution.

The optimization model as described is a nonlinear model, since total cost is a nonlinear function of service level. LINGO (a well-known general optimization package) dynamic link library (DLL) optimization functions were utilized in the decision support system (DSS) to solve the models. The DSS formulates the model structure and coefficient values in text format. The model is then passed to LINGO's optimization engine through function calls to the LINGO DLL library. Model solutions (variable and objective function values) are returned through library function calls as vector variables.

Budget planners may also be interested in how much money would be required to meet target service levels in all functions. In this case, the budget constraint is removed, and the inequality in the above service level constraints is replaced with equality conditions:

$$SL_{f,d,s} = MinSL_{f,d,s} \quad \forall \ f, d, s \tag{12}$$

In this case, the model is no longer one of optimization but of constraint satisfaction. Costs are calculated directly by using the MinSL values in the total cost functions, and the optimization process is bypassed.

DECISION SUPPORT SYSTEM (DSS) DESIGN & IMPLEMENTATION

A decision support system (DSS) was developed in Access 2000 to implement the previously discussed models. Visual Basic for Applications (VBA) and Structured Query Language (SQL) were used as the primary mechanisms for implementing model logic. The underlying table design is shown in Figure 1.

BaseData_NEEDS		
PK,I1	ID	COUNTER
	District	INTEGER
	Parish	INTEGER
	System	INTEGER
	ControlSection	VARCHAR(6)
	Length	DOUBLE
	ADT	INTEGER
	TotalConditionRating	SMALLINT
	TotalSafetyRating	SMALLINT
	TotalRating	SMALLINT
	SurfaceType	INTEGER
	PavementType	INTEGER
	BaseType	INTEGER
	LastYearImproved	SMALLINT
	YearsSinceImproved	INTEGER
	Lanes	SMALLINT

BaseData_Districts		
PK	District	INTEGER
	Description	VARCHAR(255)

BaseData_Systems		
PK	System	INTEGER
I2	SystemName	VARCHAR(50)
I3	PopulationType	VARCHAR(50)
I1	Description	VARCHAR(100)

BaseData_Parishes		
PK	ParishNumber	INTEGER
I1	ParishName	VARCHAR(17)

BaseData_FunctionEffectivenessRankings		
PK	District	INTEGER
PK,I1	ParticipantID	INTEGER
PK	System	INTEGER
PK	Objective	INTEGER
PK	Function	INTEGER
	Rank	DOUBLE

BaseData_Tolls		
PK,I1	TollID	COUNTER
	District	INTEGER
	System	INTEGER
	TollDesc	VARCHAR(100)

BaseData_ObjectiveRankings		
PK	District	INTEGER
PK,I1	ParticipantID	INTEGER
PK	System	INTEGER
PK	Objective	INTEGER
	Rank	REAL

BaseData_Function		
PK	Function	INTEGER
	FunctionName	VARCHAR(40)
	AccomplishmentUnits	VARCHAR(30)

BaseData_FerryCrossings		
PK,I1	FerryCrossingID	COUNTER
	District	VARCHAR(50)
	FerryCrossingDesc	VARCHAR(50)

BaseData_RailCrossings		
PK,I1	RailCrossingID	COUNTER
	District	INTEGER
	ADT	DOUBLE
	ConditionRating	DOUBLE
	CrossingDescription	VARCHAR(50)

BaseData_MOPS_WorkOrders		
PK	Function	INTEGER
PK	District	INTEGER
PK	FiscalYear	INTEGER
PK	Parish	INTEGER
PK	Quarter	INTEGER
PK	ControlSection	VARCHAR(50)
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE

BaseData_TrafficDevices		
PK,I1	DeviceID	COUNTER
	District	INTEGER
	System	INTEGER
	DeviceType	INTEGER

Figure 1 (a): Database table design – base data tables

	SummaryData_DistrictFunctionLevel	
PK	Function	INTEGER
PK	District	INTEGER
PK	System	INTEGER
PK	FiscalYear	INTEGER
PK	Quarter	INTEGER
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE

	SummaryData_DistrictLevel	
PK	District	INTEGER
PK	System	INTEGER
I7	NumberTolls	INTEGER
I5	NumberSignalDevices	INTEGER
I4	NumberRailroadCrossings	INTEGER
I1	NumberBridges	INTEGER
I3	NumberNonTimberBridges	INTEGER
I6	NumberTimberPileBridges	INTEGER
I2	NumberMovableBridges	INTEGER
	BridgeLength	DOUBLE
	SquareFeetConcreteDeck	DOUBLE
	Length	DOUBLE
	MilesConcrete	DOUBLE
	MilesConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneP1200ADT	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneM1200ADT	DOUBLE
	MilesComposite	DOUBLE
	MilesCompositeEquivalent2LaneP1200ADT	DOUBLE
	MilesCompositeEquivalent2LaneM1200ADT	DOUBLE
	MilesAsphalt	DOUBLE
	MilesGravel	DOUBLE
	MilesShoulderNonpavedTurf	DOUBLE
	MilesShoulderNonpavedAggregate	DOUBLE
	MilesShoulderPaved	DOUBLE
	MilesMowingUrban	DOUBLE
	MilesMowingRural	DOUBLE
	MilesSweeperCurb	DOUBLE
	PhysicalAcres	DOUBLE
	VehicleMiles	DOUBLE
	NumberLitterBarrels	INTEGER
	NumberRestAreas	INTEGER
	NumberCrashDevices	INTEGER

	BaseData_MOPS_Inventory	
I2	District	INTEGER
I3	Gang	VARCHAR(3)
I7	System	INTEGER
I1	Control	VARCHAR(3)
I6	Section	VARCHAR(2)
I5	Parish	INTEGER
I4	Loc-District	VARCHAR(2)
	Length	DOUBLE
	MilesConcrete	DOUBLE
	MilesConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2Lane	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneP1200ADT	DOUBLE
	MilesAsphalticConcreteEquivalent2LaneM1200ADT	DOUBLE
	MilesComposite	DOUBLE
	MilesCompositeEquivalent2LaneP1200ADT	DOUBLE
	MilesCompositeEquivalent2LaneM1200ADT	DOUBLE
	MilesAsphalt	DOUBLE
	MilesGravel	DOUBLE
	MilesShoulderNonpavedTurf	DOUBLE
	MilesShoulderNonpavedAggregate	DOUBLE
	MilesShoulderPaved	DOUBLE
	MilesMowingUrban	DOUBLE
	MilesMowingRural	DOUBLE
	MilesSweeperCurb	DOUBLE
	PhysicalAcres	DOUBLE
	VehicleMiles	DOUBLE
	NumberLitterBarrels	INTEGER
	NumberRestAreas	INTEGER
	NumberCrashDevices	INTEGER

	SummaryData_ControlSectionFunctionLevel	
PK	District	INTEGER
PK	Parish	INTEGER
PK	System	INTEGER
PK	ControlSection	VARCHAR(6)
PK	Function	DOUBLE
PK	FiscalYear	INTEGER
PK	Quarter	INTEGER
	UnitsAccomplished	DOUBLE
	ManhoursRegularTime	DOUBLE
	ManhoursOvertime	DOUBLE
	PersonnelCost	DOUBLE
	EquipmentCost	DOUBLE
	MaterialCost	DOUBLE
	ManhoursRegularTimeNonzeroUnits	DOUBLE
	ManhoursOvertimeNonzeroUnits	DOUBLE
	PersonnelCostNonzeroUnits	DOUBLE
	EquipmentCostNonzeroUnits	DOUBLE
	MaterialCostNonzeroUnits	DOUBLE

	SummaryData_ControlSectionLevel	
PK	District	INTEGER
PK	Parish	INTEGER
PK	System	INTEGER
PK	ControlSection	VARCHAR(6)
	Length	DOUBLE
	WeightedADT	DOUBLE
	WeightedTotalConditionRating	DOUBLE
	WeightedTotalSafetyRating	DOUBLE
	WeightedTotalRating	DOUBLE
	MilesSurfaceType1	DOUBLE
	MilesSurfaceType2	DOUBLE
	MilesSurfaceType3	DOUBLE
	MilesSurfaceType4	DOUBLE
	MilesSurfaceType5	DOUBLE
	MilesSurfaceType6	DOUBLE
	MilesSurfaceType7	DOUBLE
	MilesPavementType1	DOUBLE
	MilesPavementType2	DOUBLE
	MilesPavementType3	DOUBLE
	MilesPavementType4	DOUBLE
	MilesPavementType5	DOUBLE
	MilesPavementType6	DOUBLE
	MilesPavementType7	DOUBLE
	MilesBaseType1	DOUBLE
	MilesBaseType2	DOUBLE
	MilesBaseType3	DOUBLE
	MilesBaseType4	DOUBLE
	MilesBaseType5	DOUBLE
	MilesBaseType6	DOUBLE
	MilesBaseType7	DOUBLE
	WeightedYearsSinceImproved	DOUBLE
	WeightedLanes	DOUBLE

	BaseData_Bridges	
PK,I1	BridgeID	COUNTER
	District	INTEGER
	PierType	INTEGER
	Movable	BIT
	Length	DOUBLE
	ADT	DOUBLE
	ConditionRating	DOUBLE
	TotalSquareFeetConcreteDeck	DOUBLE
	Description	VARCHAR(50)

	SummaryData_AvgObjectiveRankings	
	District	INTEGER
	System	INTEGER
	Objective	INTEGER
	Rank	DOUBLE

	SummaryData_AvgFunctionEffectivenessRankings	
PK	District	INTEGER
PK	System	INTEGER
PK	Objective	INTEGER
PK	Function	INTEGER
	Rank	DOUBLE

	SummaryData_PriorityWeightings	
PK	District	INTEGER
PK	System	INTEGER
PK	Function	INTEGER
	Weight	DOUBLE

Figure 1 (b): Database table design – base data tables

ServiceLevels_FerryCrossings		
PK,I6	**FerryCrossingID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I5	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I4	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfPilots	INTEGER
	AvgPilotPay	DOUBLE
I2	NumberOfStaff	INTEGER
	AvgStaffPay	DOUBLE
I3	NumberOfTrips	INTEGER
	FuelCostPerTrip	DOUBLE

ServiceLevels_Restareas		
PK,I5	**RestareaID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I4	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I3	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfJanitorialStaff	INTEGER
	AvgJanitorialPay	DOUBLE
I2	NumberOfSecurityStaff	INTEGER
	AvgSecurityStaffPay	DOUBLE

ServiceLevels_Tolls		
PK,I5	**TollID**	**INTEGER**
PK	**DayofWeek**	**INTEGER**
PK,I4	**ShiftID**	**INTEGER**
	ShiftStartTime	DATETIME
	ShiftEndTime	DATETIME
I3	NumberSupervisoryStaff	INTEGER
	AvgSupervisoryPay	DOUBLE
I1	NumberOfCollectors	INTEGER
	AvgCollectorPay	DOUBLE
I2	NumberOfSecurityStaff	INTEGER
	AvgSecurityStaffPay	DOUBLE

ServiceLevels_Functions		
PK	**Function**	**INTEGER**
PK	**District**	**INTEGER**
PK	**System**	**INTEGER**
	ServiceLevel	VARCHAR(50)

UAR_Variables		
PK,I1	**Variable**	**COUNTER**
U1	VariableName	VARCHAR(100)
	Source	VARCHAR(50)
	FieldName	VARCHAR(100)
	SASname	VARCHAR(100)
	Description	LONGCHAR

UAR_ModelCoefficients		
PK	**District**	**INTEGER**
PK	**Quarter**	**INTEGER**
PK	**System**	**INTEGER**
PK	**Function**	**INTEGER**
PK	**Variable**	**INTEGER**
	UAR_Coefficient	DOUBLE
	Rsquared	DOUBLE
	ChiSquare	DOUBLE

UAR_FunctionVariableMap		
I2	VariableName	VARCHAR(100)
I1	FunctionCode	INTEGER
	State	INTEGER
	OrdinalValue	INTEGER

Figure 1 (c): Database table design – service level and UAR tables

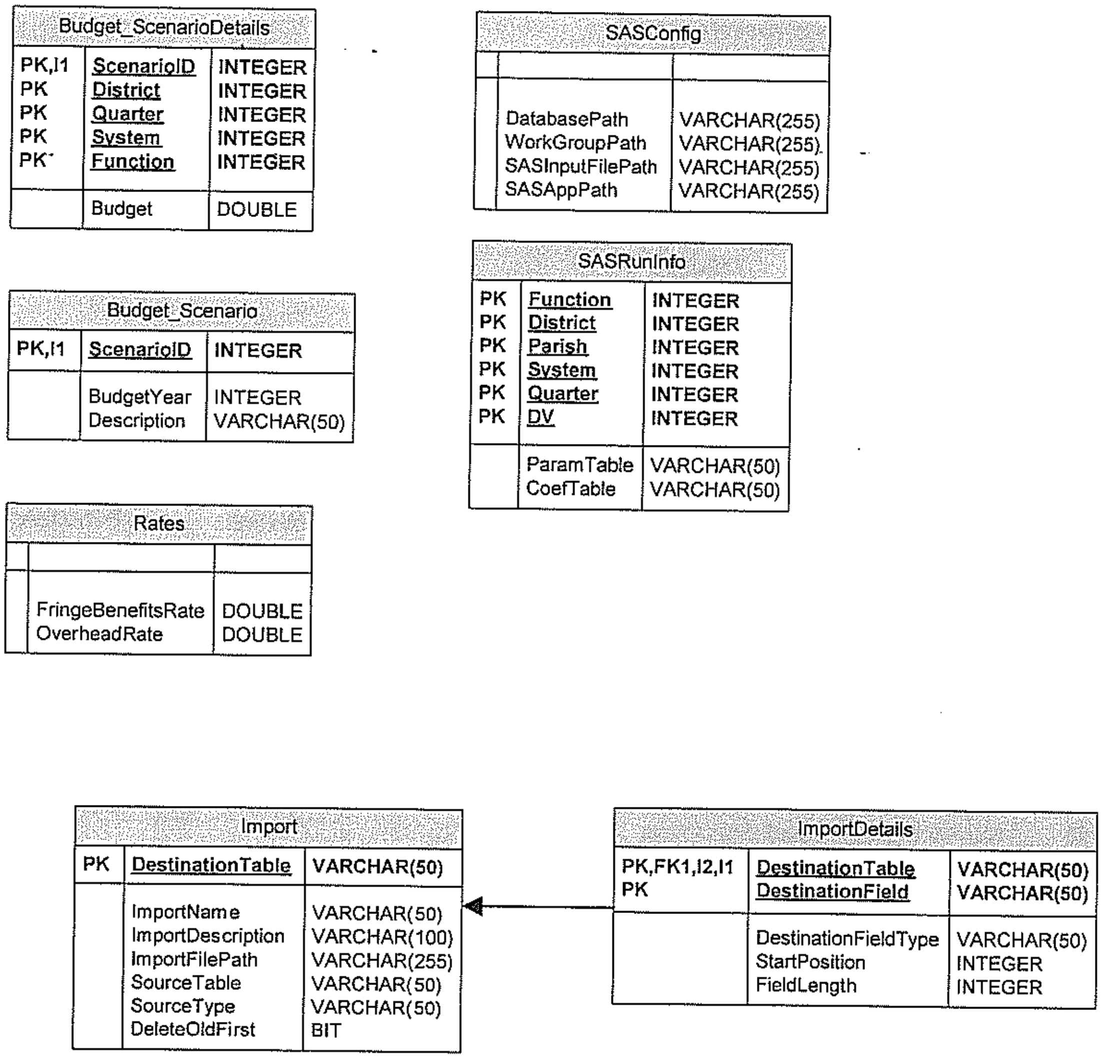

Figure 1 (d): Database table design – budget, SAS, and import tables

Startup

On startup of the DSS, the following splash screen (Figure 3) is displayed.

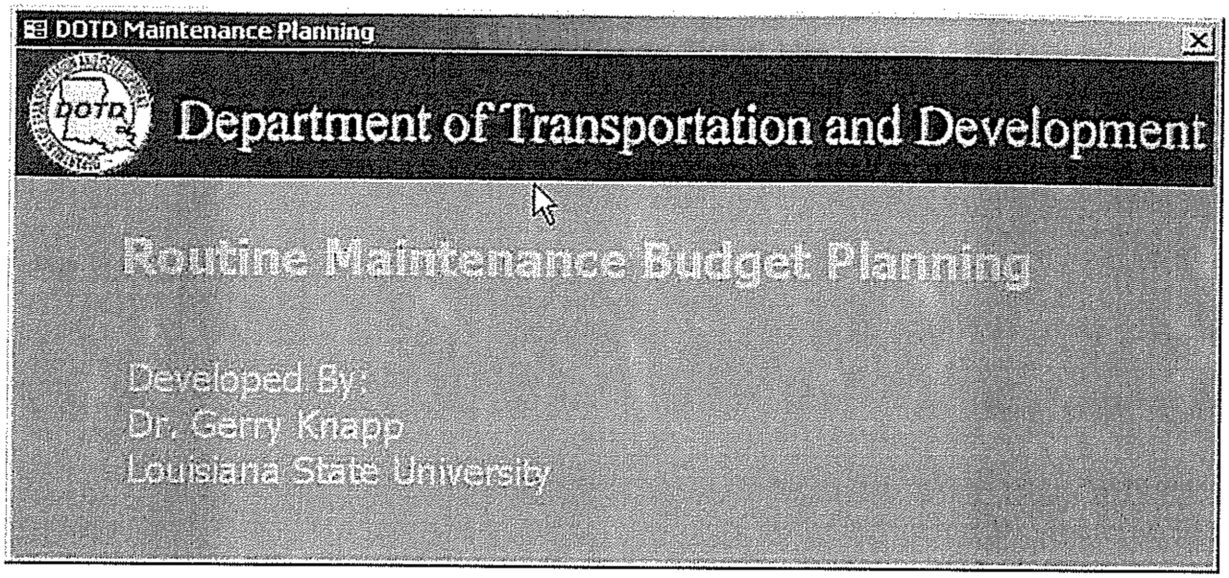

Figure 2: Splash screen

The splash screen closes automatically within 3 seconds. The planner is then presented with the following menu system (Figure 3-9)

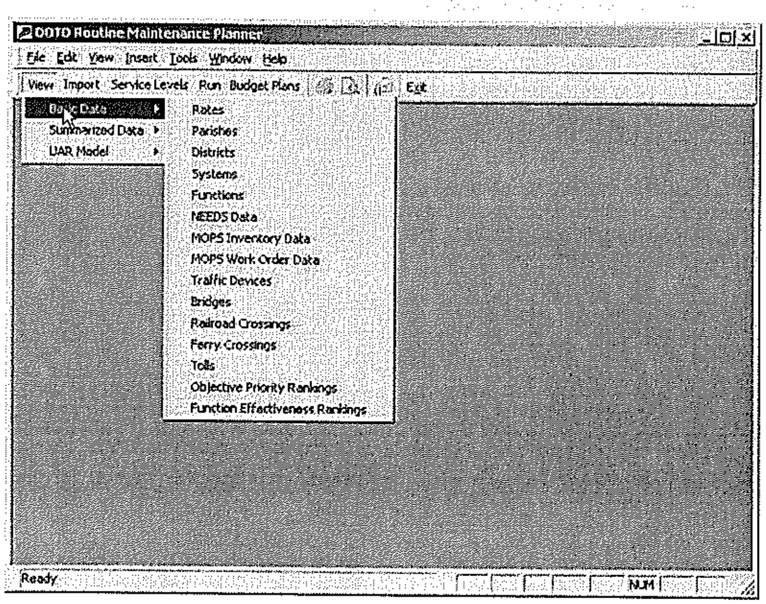

Figure 3: Menu system – view base data

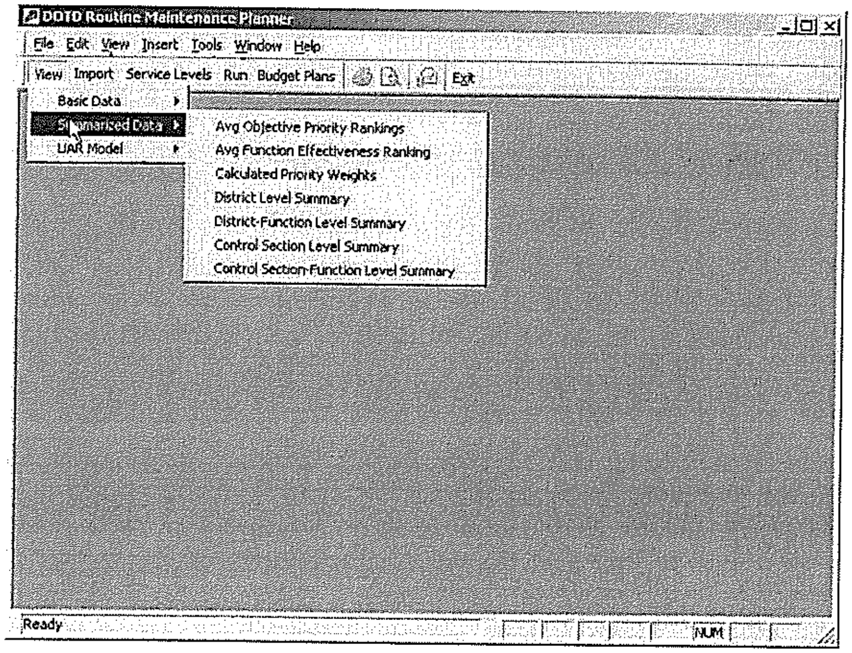

Figure 4: Menu system – view summary data

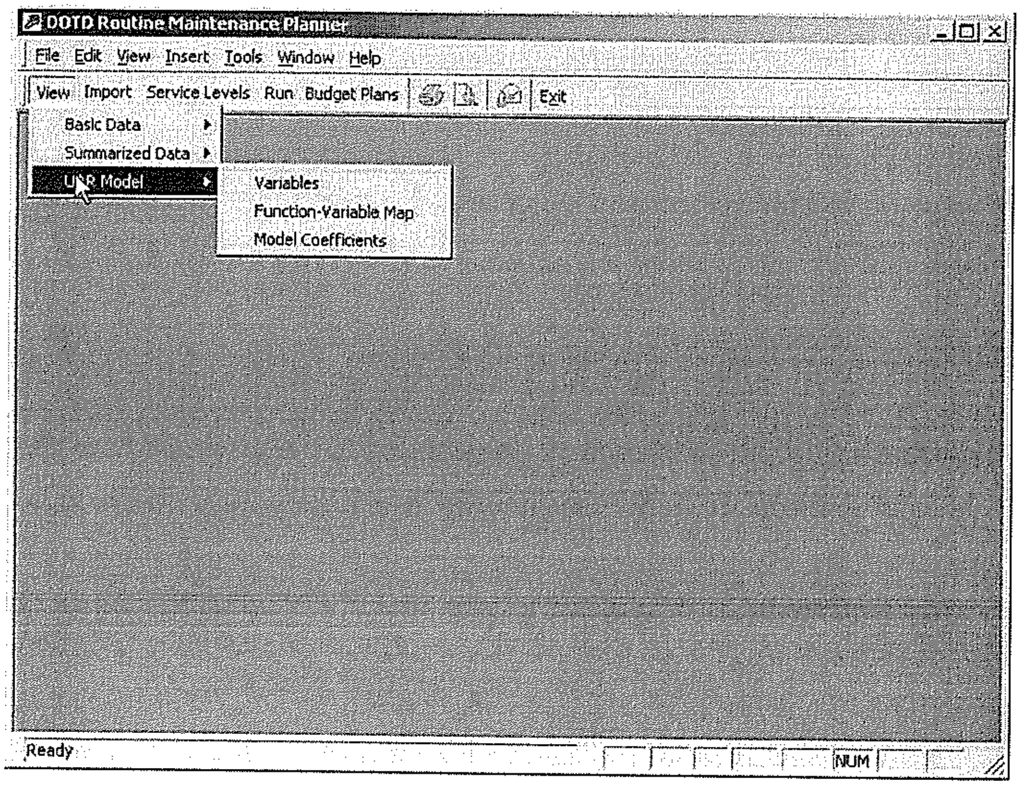

Figure 5: Menu system – view unit model data

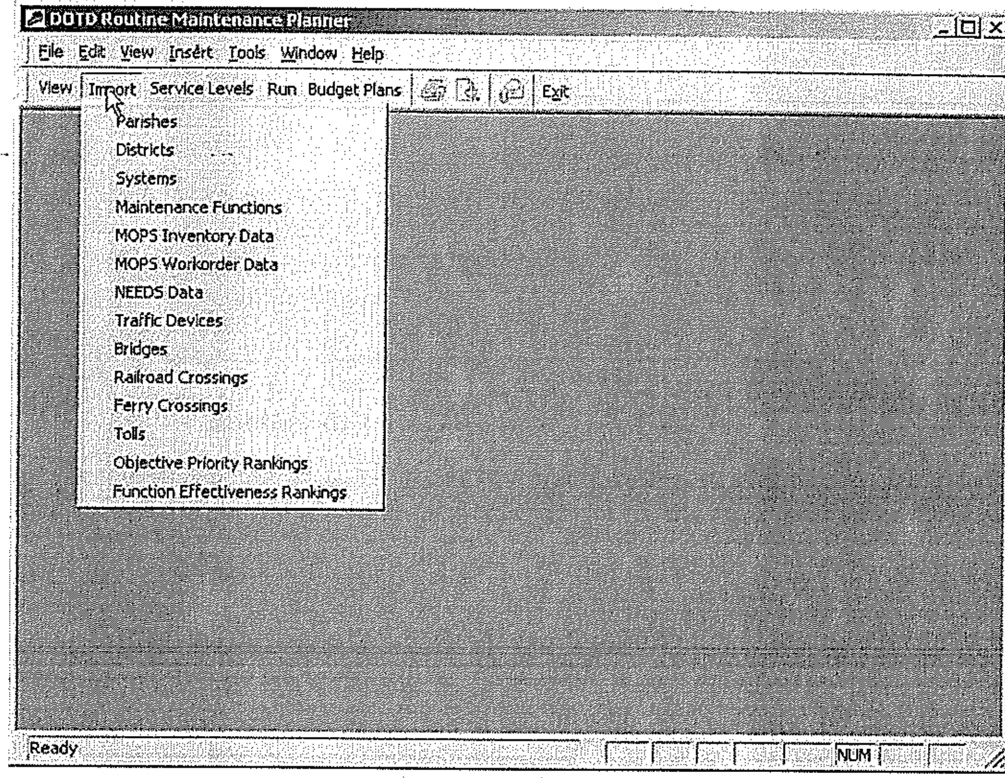

Figure 6: Menu system – import options

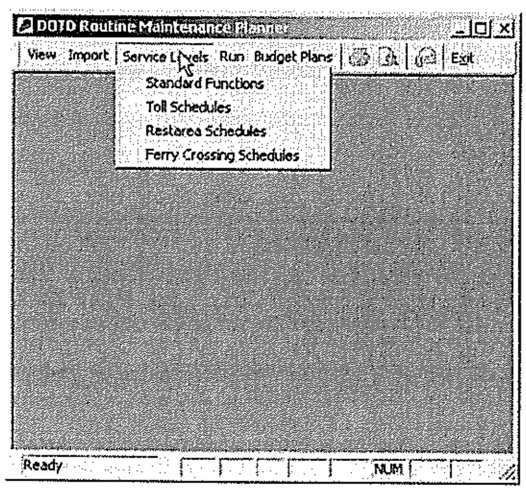

Figure 7: Menu system – service level settings

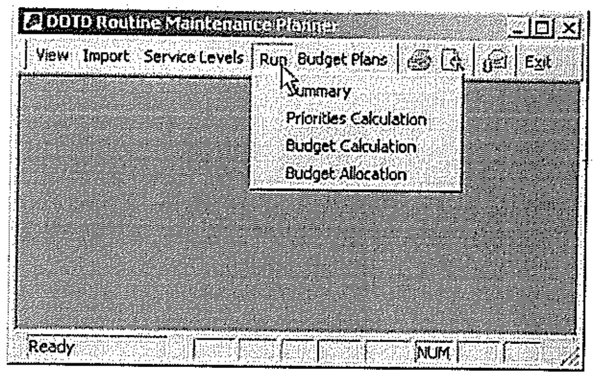

Figure 8 : Menu system - run options

View Menu

Basic information on parishes, districts, and maintenance functions can be viewed and edited by selecting the corresponding option from the menu. The corresponding forms are shown in Figures 10-12.

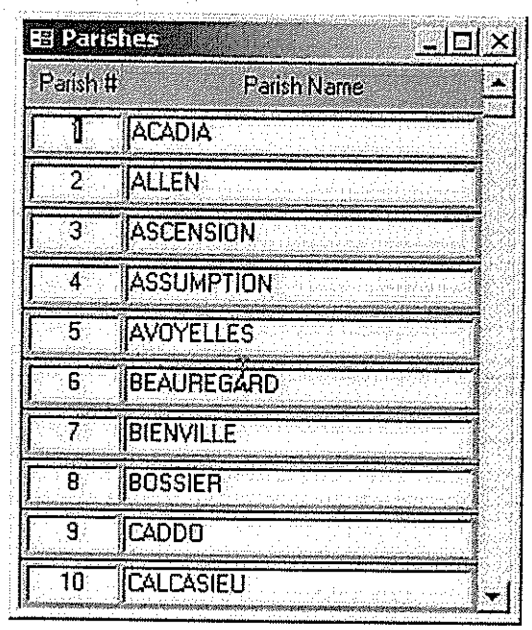

Figure 9: Parishes form

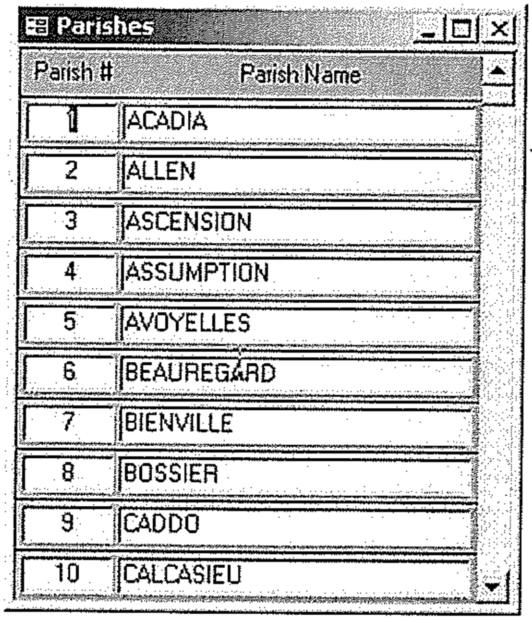

Figure 10: Districts form

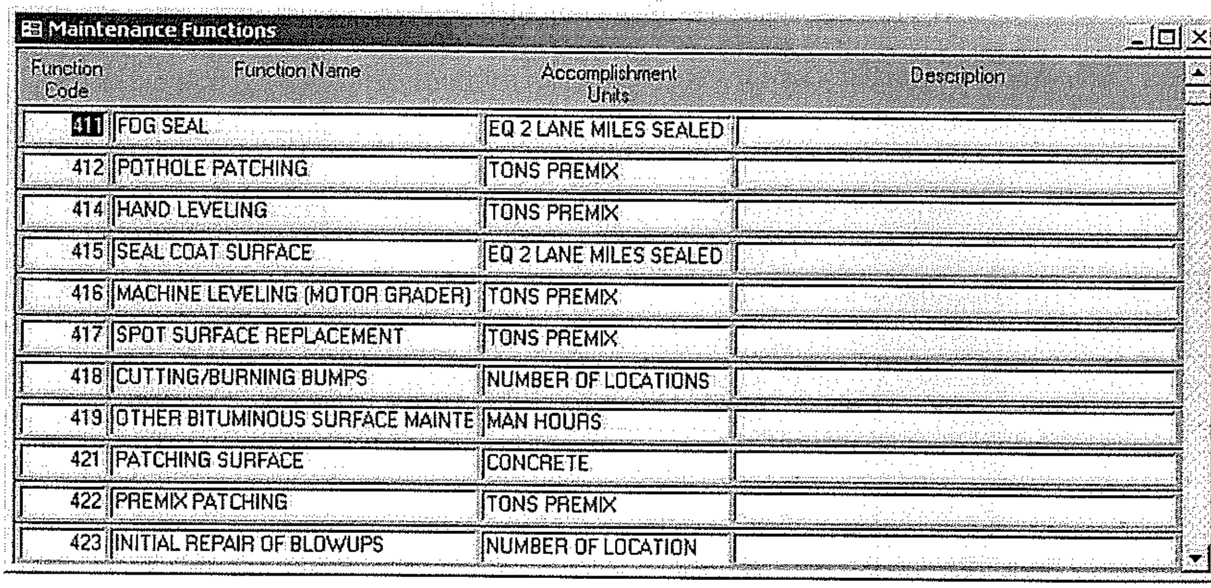

Figure 11: Maintenance functions form

Imports Menu

Selecting imports from the menu brings up a submenu where you can select what data to import. Once the import type is selected, an import form will come up with the import specification. The form allows the user to enter the format once and have the information saved. Figure 8 shows an example of a text file import specification. Figure 9 shows an example of a database import specification. The import form also supports importing from

Excel spreadsheets. For databases and spreadsheets, the table or sheet must match column for column with the destination table.

The following base data items can be imported:

- Maintenance Functions
- Parishes
- Districts
- Systems
- Needs
- MOPS Work Orders
- MOPS Inventory
- Structures
- Traffic Devices
- Tolls
- Ferry Crossings
- Objective Priority Rankings
- Function Effectiveness Rankings
- SAS Stepwise Regression Results

On import, any prior data will either be overwritten/appended-to or deleted, depending on whether the delete option is unchecked or checked respectively. When the delete option is off, new data that matches an old record will overwrite the old record, otherwise it will be added as a new record.

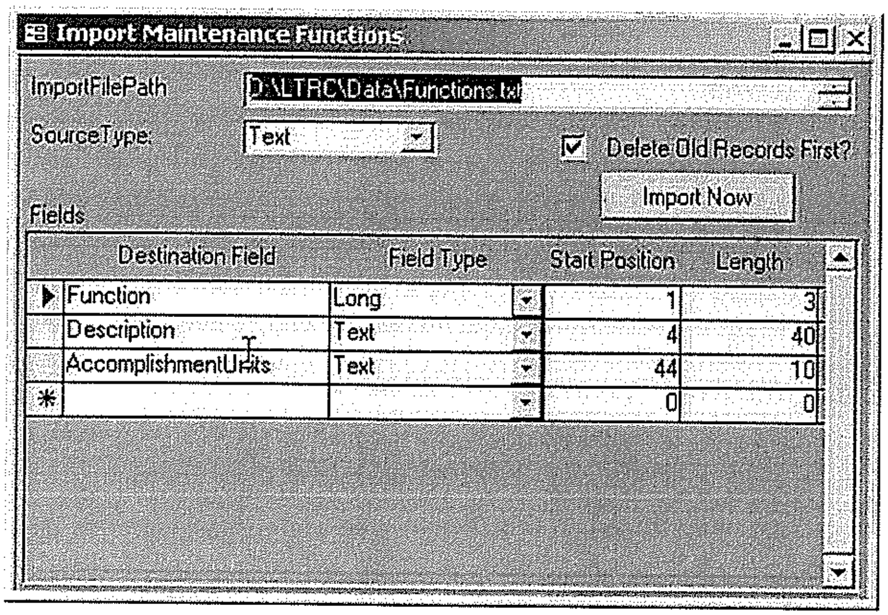

Figure 12: Import form – text file specification

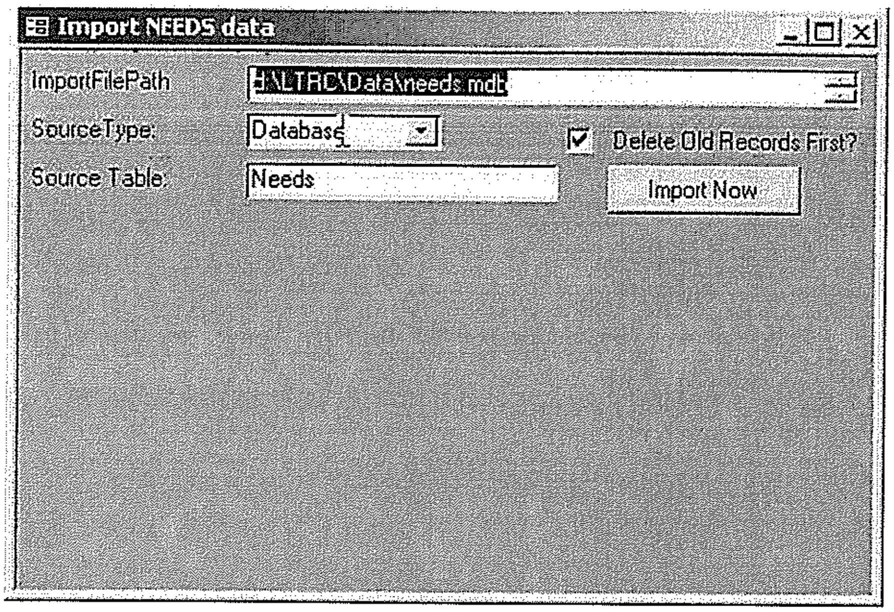

Figure 13: Import form – database table specification

Service Levels Menu

The service levels menu gives the user the ability to create and revise multiple service level scenarios in each of the following categories:

- *Standard functions*. Define service level scenarios for all functions whose service level is not defined in terms of employee schedules.

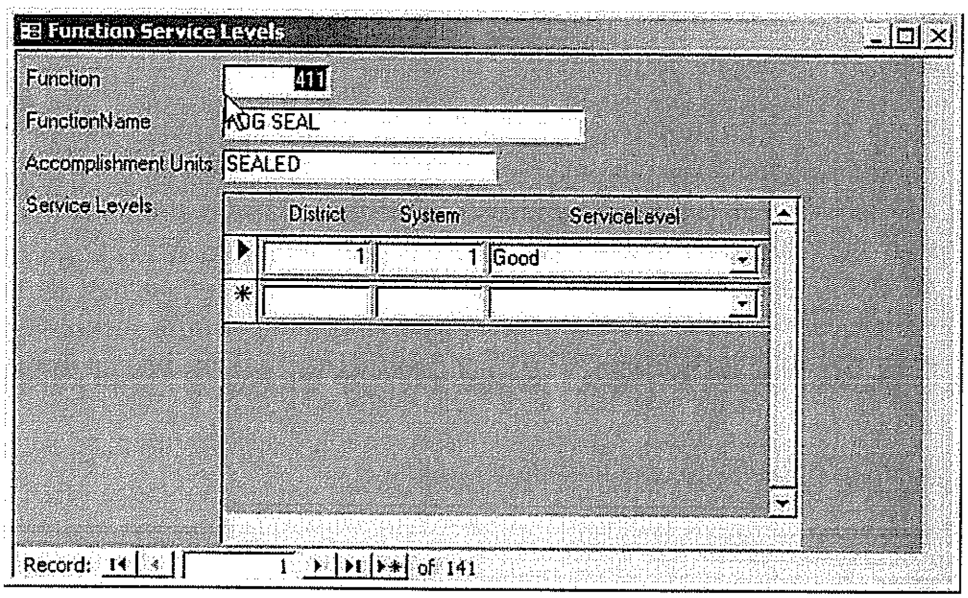

Figure 14: Function service levels form

- *Ferry Crossing Schedules.* Define staffing level scenarios for ferry crossings

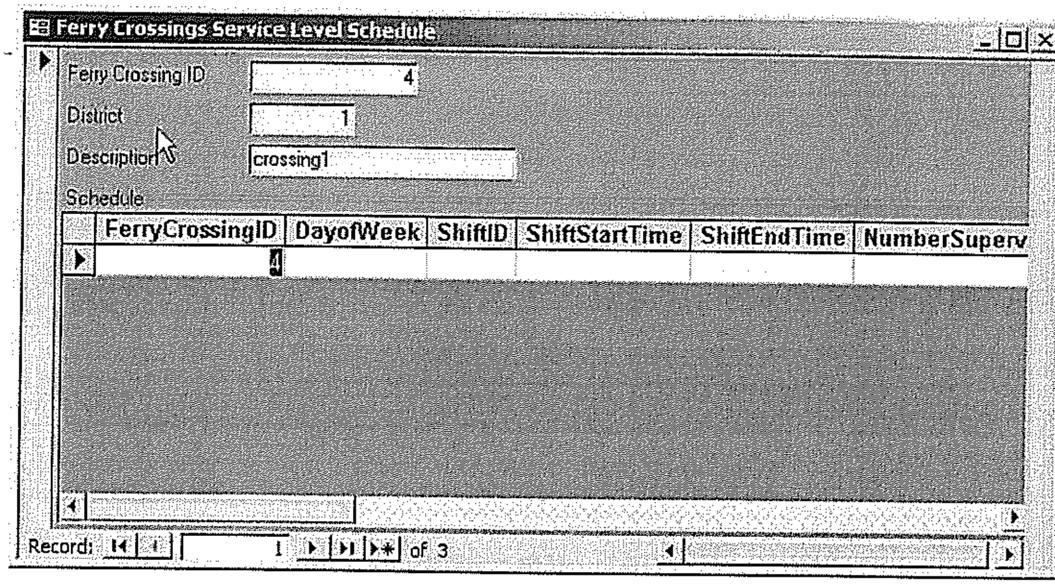

Figure 15: Ferry crossings service level form

- *Toll Schedules.* Define staffing level scenarios for tolls. The form format is similar to that for ferry crossings.

- *Rest area Schedules.* Define staffing level scenarios for rest areas. The form format is similar to that for ferry crossings.

Run Menu

The run menu provides the following sub items:

- *Summarize.* The summarize command is used to run data summaries and integration on all base data. The summaries calculated are discussed under "Data Collection" in this section. Any previous summary is first cleared. Before running this command, the user should be sure that all base data has been imported and is up to date; otherwise, an error might be generated or the summary might reflect out of date values. A message is displayed when it has completed, or if an error is encountered. The district level and control section level summary forms are both opened up as well for review.

- *Priorities Calculation.* Calculates the function/district/system priority weights, and displays the priority weights when completed.

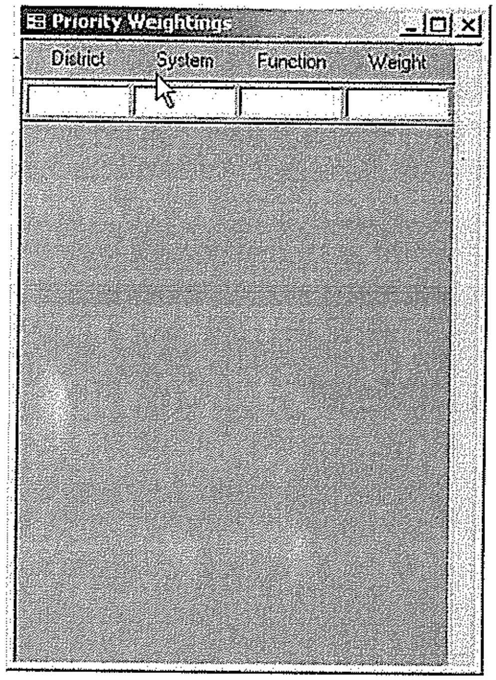

Figure 16: Priority weightings

- *Budget Calculation.* Calculates the budget plan for a specified service level scenario. Assumes budget is unconstrained.
- *Budget Allocation.* Runs the allocation optimization model for a specified service level scenario and budget constraint.
- *Fit Unit Accomplishment Rates.* Performs linear regression analysis across a specified date range to recalculate the unit accomplishment prediction model coefficients. displays the unit accomplishments rates summary form when completed.

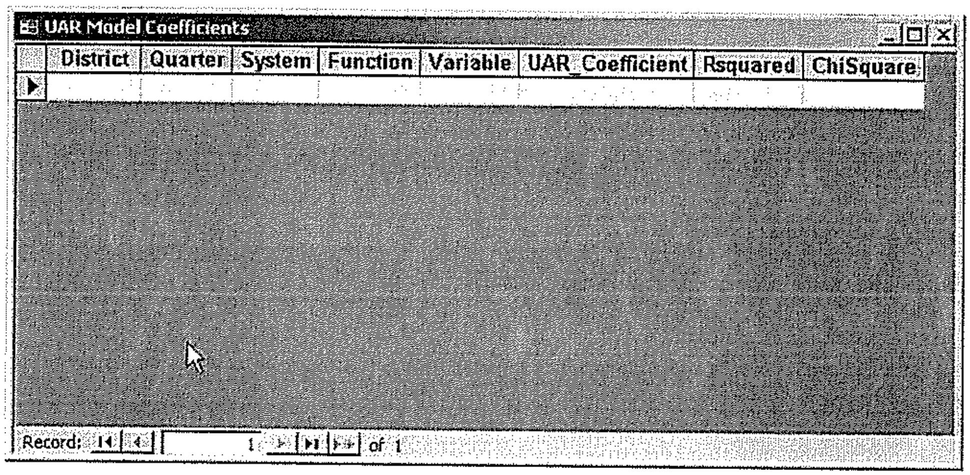

Figure 17: UAR model coefficients form

- *Run SAS Stepwise Regression Model.* Displays the SAS configuration Form. "Run" outputs data in a SAS program format for running the SAS stepwise regression model to select variables for the unit accomplishment rates model, calls SAS to execute the model (this assumes SAS is installed on the same machine), and loads in the resulting unit accomplishment rates (note: this replaces the existing model).

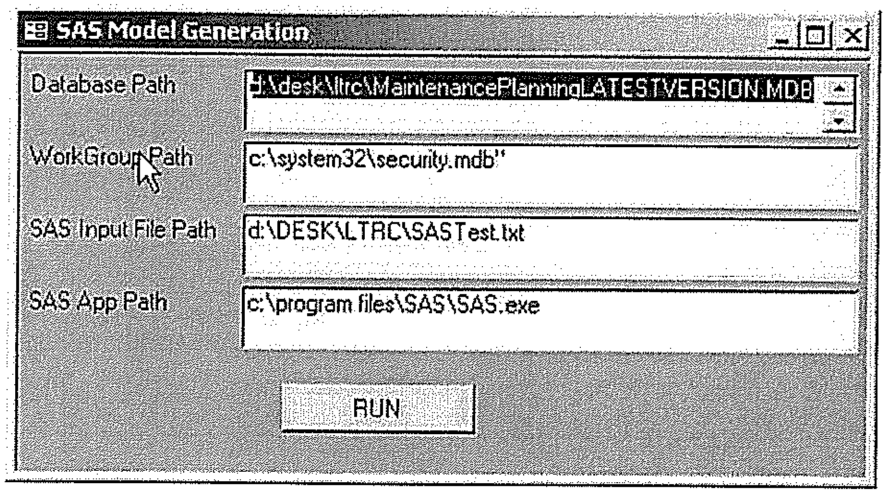

Figure 18: SAS model generation form

Budget Plans

The budget plans menu item allows the user to review previously calculated and stored budget plans. This provides an opportunity to do what-if type analyses and compare the results.

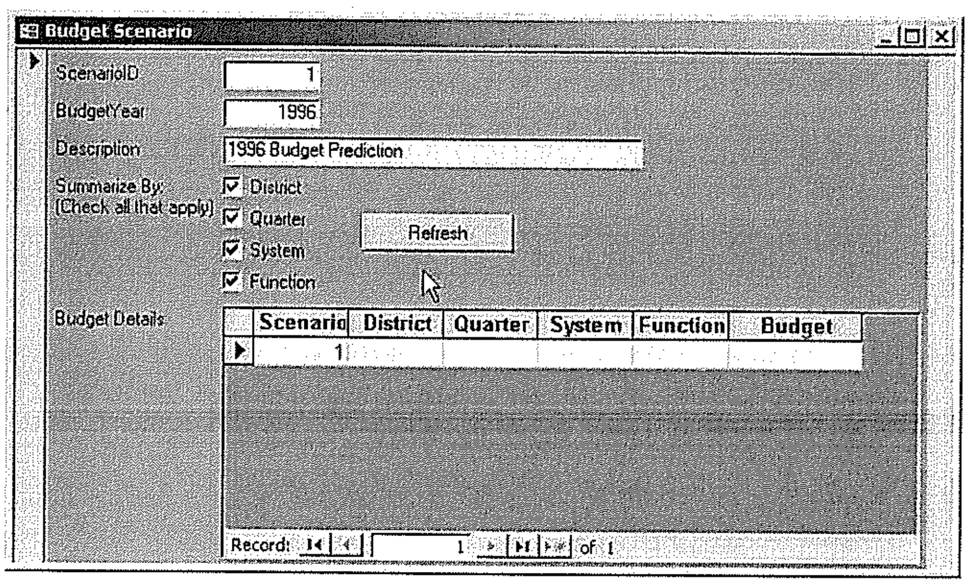

Figure 19: Budget scenarios form

Other Menu Items

Menu options for printing, print preview, emailing, and exiting are also provided on the main menu.

Validation

To test the robustness of the DSS, the following test cases were used:

Table 4: Test cases

CASE	MODEL FIT TO	YEAR PREDICTED	OTHER ASSUMPTIONS
1	1998 Fiscal Year (for AUA) 1997-98 FY (for UAR)	1999 Fiscal Year	2.5% inflation (labor, materials, and equipment). All functions had equal priorities. Service levels same as prior year.
2	1999 Fiscal Year (for AUA) 1998-99 FY (for UAR)	2000 Fiscal Year	Same as case 1

It should be noted that we did not have the exact inventory and NEEDS data available during these fiscal years (we had this data for 1995 and 2001 only). Differences between 1995 and 2001 were interpolated to the respective years being fit/predicted.

For each case the AUA and UAR models were fit to the fiscal years indicated. A prediction was then calculated and compared in total and by quarter, district, and system, against the actual budget incurred in the predicted fiscal year.

The model produced reasonable results, with an average error of 5.3% (low) over the two test cases.

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